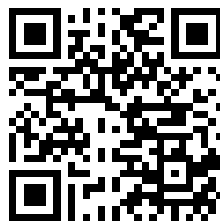


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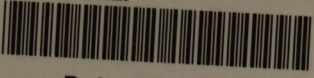
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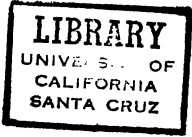


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*WAR DEPARTMENT TECHNICAL MANUAL*

*TM 9-2601*

This TM supersedes WD Pamphlet No. 1065, Elementary Optics and Applications to Fire Control Instruments, dated January 1924, and Ordnance School Text (TM 9-2601), Elementary Optics, dated December 1942.

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22737

*INSTRUCTION GUIDE:*

**ELEMENTARY OPTICS**  
**and**  
**Applications to**  
**Fire Control Instruments**



*WAR DEPARTMENT*

• *19 APRIL 1945*

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(See also paragraph 23b, AR 380-5, 15 March 1944.)

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**WAR DEPARTMENT**  
**Washington 25, D. C., 19 April 1945**

**TM 9-2601 Instruction Guide: Elementary Optics and Applications to Fire Control Instruments, is published for the information and guidance of all concerned.**

[ A.G. 300.7 (19 Jun 44)  
O.O. 300.7/3557 ]

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**(For explanation of symbols, see FM 21-6.)**

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**Figure 1 – Military Applications of Optics**

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This TM supersedes WD Pamphlet No. 1065, Elementary Optics and Applications to Fire Control Instruments, dated January 1924, and Ordnance School Text (TM 9-2601), Elementary Optics, dated December 1942.

**CHAPTER 1 — INTRODUCTION**

**1. SCOPE.**

a. This manual is published primarily for the information and guidance of ordnance maintenance personnel and others who must be familiar with the functioning of fire control instruments.

b. This manual covers the basic principles of optical theory necessary to understand the operation of fire control instruments. It contains descriptive matter and illustrations sufficient to provide a general knowledge of the principles upon which the design and construction of military optical instruments are based.

## CHAPTER 2 — PROPERTIES OF LIGHT

### Section I

### LIGHT

#### 2. THEORIES OF LIGHT.

a. **General.** The true nature of light and the manner in which it travels has fascinated scientific investigators for centuries. Many theories have been advanced to explain why light behaves as it does. Later discoveries have proved some of these theories unsound. This manual cannot attempt to cover all the aspects of light nor is this knowledge essential to the study of the laws of optics as they apply to fire control equipment. Therefore, only a short summary of the various theories of light is given.

b. **Ancient Greek Theory.** The earliest known speculations as to the nature of light were those of the ancient Greeks. They believed that light was generated by streams of particles which were ejected from the human eye. This theory could not persist because it could not explain why one could not see as well at night as by day.

c. **Newton.** The first modern theory was that of Sir Isaac Newton (1643—1727). This, the *corpuscular* theory, assumed light to be a flight of material particles originating at the light source. Newton believed that light rays moved at tremendous velocity in a state of near vibration and could pass through space, air, and transparent objects. This theory agreed with the property of light to move only in a straight line, but failed to explain other phases of light behavior. Newton stumbled on light interference in his discovery of Newton's Rings (par. 47), but did not realize their significance.

d. **Huygens.** In Newton's time, Christiaan Huygens (1629—1695) attempted to show that the laws of reflection and refraction of light could be explained by his *theory of wave motion of light*. While this theory seemed the logical explanation for some phases of light behavior, it was not accepted for many years because a means was lacking by which to transmit the waves. Huygens proposed that a medium, which he called "ether," be accepted as existing to serve light rays as water does the familiar waves of water. He assumed this medium to occupy all space, even that already occupied by matter.

e. **Young and Fresnel.** Experiments made about 50 years later by Thomas Young (1773—1829), Fresnel (1788—1827), and others supported the wave theory, and the rival corpuscular theory was virtually abandoned. These scientists offered their measurement of light waves as proof, and proposed that the short wave length of light accounted for the fact that light rays cannot pass around obstacles. They accepted the "ether" theory and assumed light to be an elastic wave of energy transmitted by ether.

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*Properties of Light*

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f. **Maxwell, Boltzmann, and Hertz.** That light and electricity were similar in radiation and speed was proved by experiments of Maxwell (1831-1879), Boltzmann (1844-1906), and Hertz (1857-1894). From these experiments was developed the *Electromagnetic Theory*. These experiments produced electric current of short wave lengths that were unquestionably of electromagnetic origin and had all the properties of light waves. The Maxwell theory contended that energy was given off continuously by the radiating body.

g. **Planck.** For a time, it was thought that the puzzle of light had been definitely solved but, in 1900, Max Planck refuted the Maxwell theory that the energy radiated by an ideal radiating body was given off continuously. Instead, Planck assumed that energy was given off in very small particles which, while invisible, were grains of energy just as much as grains of sand. He called these units *quanta* and his theory the *Quantum Theory*. He contended that the radiating body contained a large number of tiny oscillators, possibly due to the electrical action of the atoms of the body. The energy radiated could be high frequency and with high energy, or low frequency and of low energy value, all possible frequencies being represented. Quanta set free was assumed to move from the source in waves.

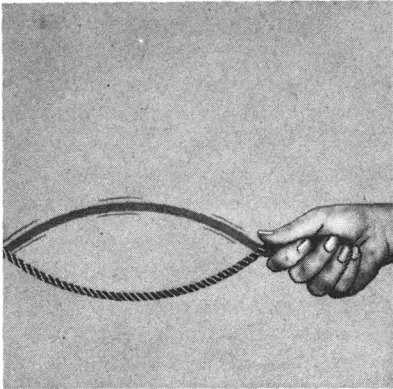
h. **Einstein.** A few years later, Albert Einstein backed up Planck and contended that the light quanta when emitted retained their identity as individual packets of energy.

i. **Millikan and Compton.** Still later, R. A. Millikan's very accurate measurements proved that the energy due to motion (called "kinetic energy") of corpuscles of light (called "photo-electrons" or "photons") behaved as assumed by the Quantum Theory. Later proof was given by A. H. Compton in 1921 in determining the motion of a single electron and a photon before and after collision of these bodies. He found that both have kinetic energy and momentum and that they behave like material bodies. This was somewhat a return to the old corpuscular theory.

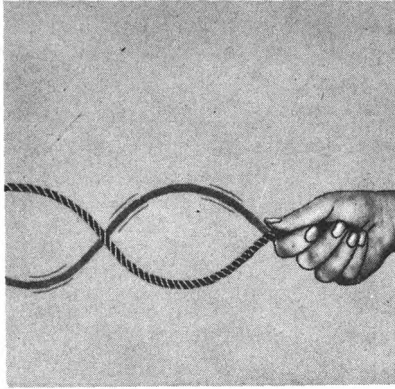
j. **Summary.** It is now believed that both the corpuscular-quantum and the wave theories of light have a sound basis and that perhaps light is dualistic in nature. Certain phases of light behavior are better explained by one or the other theories. Both theories generally assume that light travels in a wave motion and that light and electricity have much in common. The wave theory will be used in the remainder of this manual.

### 3. KNOWN FACTS ABOUT LIGHT.

a. All forms of light obey the same general laws. Light travels in waves in straight lines and at a definite and constant speed, provided it travels in a medium or substance of constant density. Upon striking a different medium, light either will bounce back (be reflected) or it will enter the medium. Upon entering a transparent

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Figure 2 — Wave Carrying Energy Along      Figure 3 — Wave Train Passing Along Rope  
Rope

medium, its speed will be slowed down if the medium is more dense, or increased if the medium is less dense. If it strikes the medium at an angle, its course will be bent (refracted) upon entering the medium. Upon striking certain mediums, more or less of the light is absorbed.

b. **Transmission of Wave Energy.** Visible light is one of many forms of *radiant energy* which is transmitted in waves. The means by which the waves carry the energy can be illustrated in a simple manner. Secure one end of a rope to some object. Hold the other end of the rope, stretch it fairly taut and shake it. A wave motion (wave pulse) will pass along the rope from the end that is held to the end that is secured (fig. 2). If the end of the rope is continually shaken, a series of waves (wave train) will pass along the rope (fig. 3). It will be noted that the different parts of the rope (the medium) vibrate successively, each bending back and forth about its own position. The disturbance travels but the medium does not. Only the energy is carried along the rope. Now imagine that the light source is a vibrating ball from which a countless number of threads extend in all directions. As the ball vibrates, successive waves are transmitted out the threads in all directions. In a similar manner, light radiates from its source.

c. **Electromagnetic Spectrum.** Heat and radio waves, light waves, ultraviolet and infrared rays, X-rays, and probably cosmic rays are various forms of radiant energy of different wave lengths and frequencies. Together, they form what is known as the *electromagnetic spectrum* (fig. 4). The visible light portion of the electromagnetic spectrum consists of wave lengths from 0.00038 to 0.00066 millimeter. The different wave lengths represent different colors of light. Practically all light is made up of many colors, each color



Properties of Light

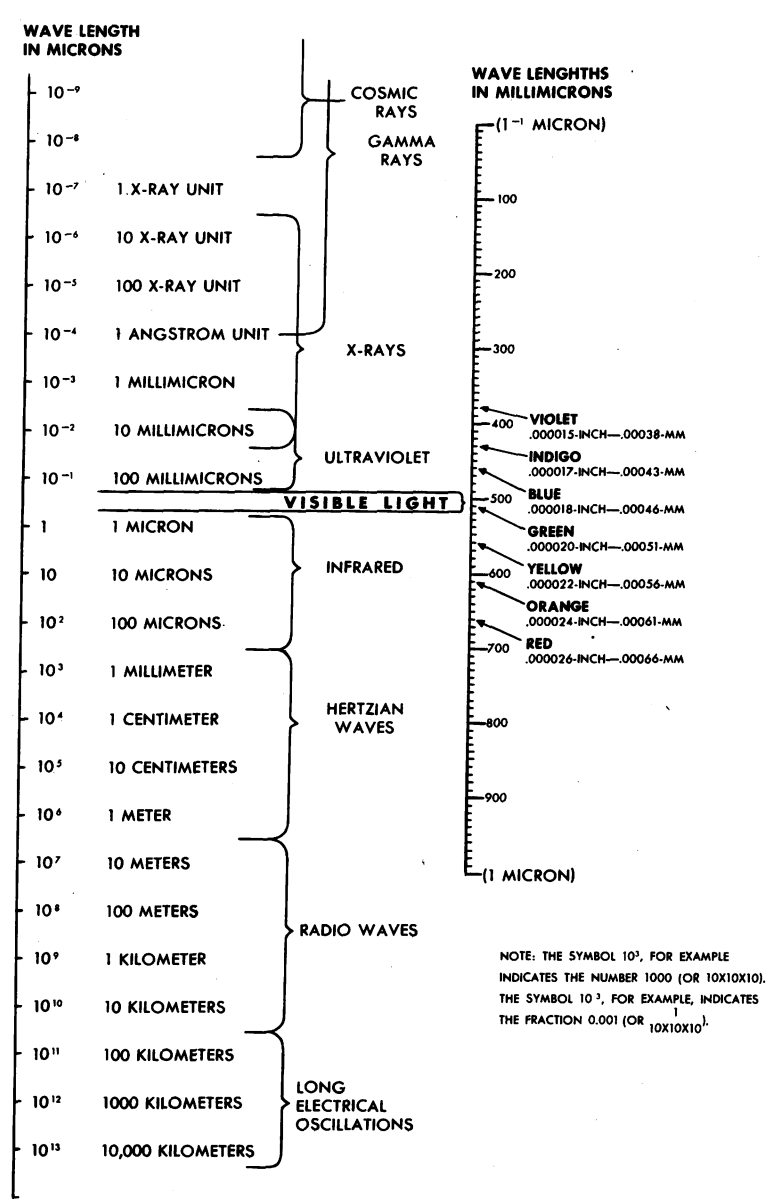
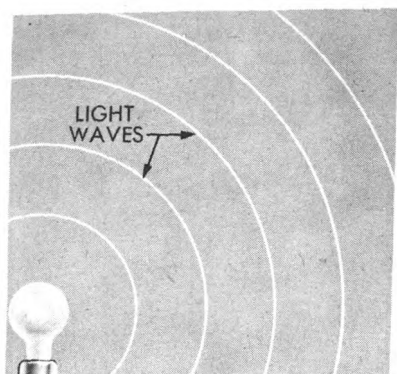
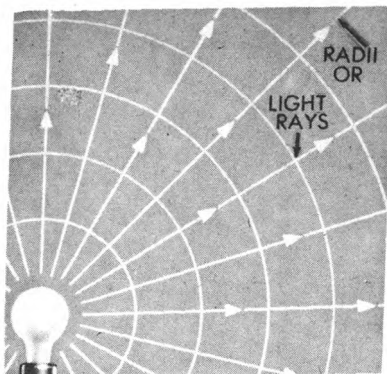


Figure 4 - Electromagnetic Spectrum

*Properties of Light*

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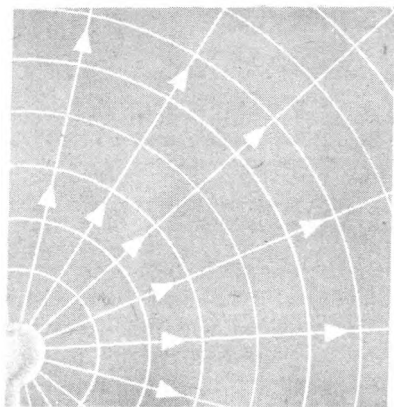
**Figure 5 — Light Sources Send Waves in All Directions**

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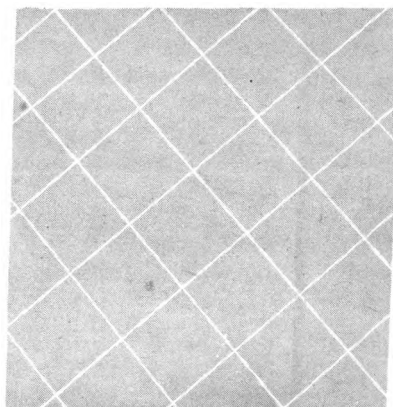
**Figure 6 — Light Travels in Direction of Radii of Waves**

having its distinctive wave length or frequency. Inasmuch as light of each color reacts in a slightly different manner when passed through different mediums, provision must be made in optical elements to control the action of light of various colors.

d. **Light Rays.** In considering visible light, assume that it starts from a luminous point and travels outwardly in all directions in waves through a medium of constant density to form a sphere of which the luminous point is the center (fig. 5). The direction in which the light is traveling is along the radii of the sphere of light (fig. 6) at

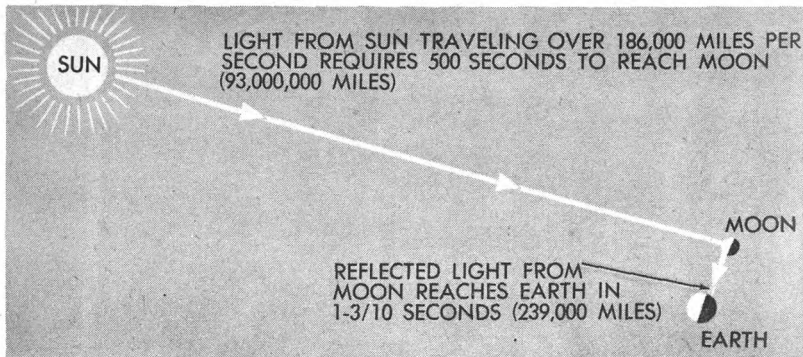


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**Figure 7 — Waves and Radii From Nearby Light Source**

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**Figure 8 — Waves and Radii From Distant Light Source**

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**Figure 9 — Speed of Light**

right angles to the fronts of the waves or the wave fronts. Light traveling along these radii are termed *light rays*.

e. **Light Rays From Distant Source.** The wave front radiating from a light source is curved when it is near the source (fig. 7), and the radii of the waves diverge or spread. The wave front becomes less and less curved as the waves move outwardly, eventually becoming almost straight (fig. 8), and the radii of waves from a distant source are virtually parallel.

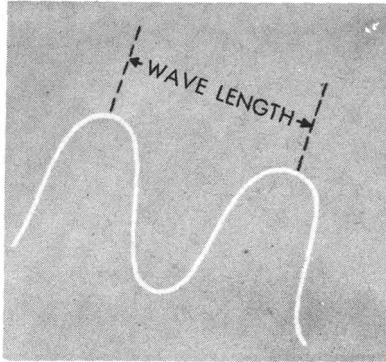
f. **Principle of Reversibility of Light Paths.** If light is reflected or refracted in any combination through a number of optical elements, it will retrace its path through the elements if the light were to enter the optical system from the other end. This is true, no matter how many reflections and refractions the light has undergone.

#### 4. SPEED OF LIGHT.

a. The speed of light is an important measurement in the study of optics. The lengths of all waves in the electromagnetic spectrum (fig. 4) are based on this measurement (par. 5). The difference in the speed of light through air, glass, and other substances accounts for the bending of light rays or refraction.

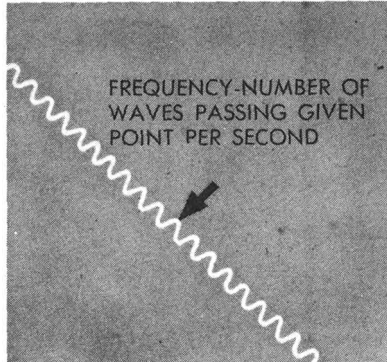
b. Light travels so fast that it was a long time before its speed could be measured. Galileo Galilei (1564—1642) tried to measure light velocity by means of blinking lanterns on widely distant hill-tops, but, as the speed was too great to be measured by this method, the velocity of light was presumed to be infinite.

c. Thirty-four years after Galileo's death, Olaus Roemer (1644—1710) determined the approximate speed of light by astronomical means based on observations which showed the amount of time re-

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RA PD 30213

Figure 10 — Wave Length



RA PD 30214

Figure 11 — Frequency

quired for the light of the planet Jupiter to cross the orbit of the earth.

d. It was nearly 200 years before scientists were able to measure a speed so great as that of light by laboratory methods. In 1849, Fizeau (1819—1896) measured the velocity of light, using intermittent flashes of light sent out by a swiftly moving toothed wheel and reflected back to the observer. Other methods, employing the reflections from rotating mirrors and prisms, have since been used to establish the speed of light to an exactness beyond that required for practical usage.

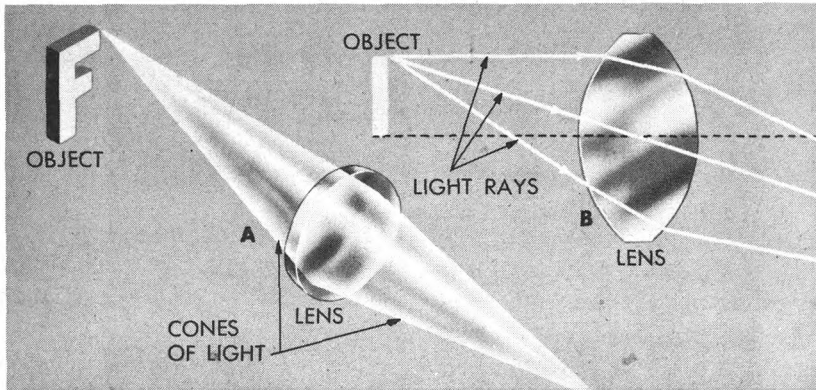
e. The speed of light is accepted as 186,000 miles per second. This is the figure used in computations involving the speed of light. The speed of light obtained by the important methods of the past 70 years ranges from 186,410 to 186,276 miles per second.

## 5. WAVE LENGTH AND FREQUENCY.

a. The *wave length* is the distance from the crest or top of one wave to the crest of the next (fig. 10). The velocity of all forms of electromagnetic waves is the same, that is, the speed of light, approximately 186,000 miles per second. The wave lengths, however, vary greatly.

b. The *frequency* is the number of waves occurring per second. It is determined by dividing the speed of light by the wave length. It may be assumed to be the number of waves passing a given point in 1 second (fig. 11).

c. Wave lengths range from many miles long to those measured in trillionths of an inch. The measurements cover such a wide range, and the shorter wave lengths are so minute, special units of measurement have been provided to avoid long decimal fractions of millimeters or inches.

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**Figure 12 — Symbols and Types of Illustrations Used in This Manual**

d. **Special Units of Measurement Employed in Measuring Wave Lengths.** The first of the special units of measurement is the *micron*, which is abbreviated to  $\mu$ , the Greek letter "M" or "Mu." It represents one one-thousandth of a millimeter. The next is variously called the *millimicron*, *micromicron*, and *micromillimeter*. It is abbreviated to  $\mu\mu$ , or "mu mu." It represents one one-millionth of a micron or one one-billionth of a millimeter.

e. Another important measurement is the Angstrom unit (*AU*), which is one-tenth of a millimicron or one ten-millionth of a millimeter. Even Angstrom units are inconveniently long in measuring the shortest electromagnetic waves so the X-ray unit (*XU*) is used for this purpose. It is one one-thousandth of an Angstrom unit or one ten-billionth of a millimeter.

**6. LIGHT RAYS AND OTHER SYMBOLS USED IN DIAGRAMS.**

a. Every point of light on a luminous body or an illuminated object sends out a constant succession of wave fronts in all directions. The action of light in passing through a lens, for example, might be as shown in A, figure 12. But for simplicity, light will be indicated in this manual by one, two, or more representative "light rays." These "light rays" are shown as white lines with arrowheads indicating the direction of travel, and are shown against dark backgrounds as in B, figure 12. Wherever possible, light will be indicated as coming from the left side of an illustration.

b. Single rays of light do not exist. The term "light ray," is used throughout this manual for the sake of clarity and convenience to indicate the direction of travel of light.

c. In studying the diagrams, it must be remembered that printed illustrations have only height and width (B, fig. 12) while everything,

### Properties of Light

including light, has three dimensions: height, width, and depth. The reader's imagination must be employed to give the illustration depth. Thus, for example, where two light rays are used to indicate the course of light from a luminous or illuminated point, these light rays indicate a solid cone of light from that point (A, fig. 12). In certain of the illustrations, an attempt has been made to simulate height, width, and depth by preparing the diagrams to appear as though viewed from an angle (A, fig. 12).

d. The letter "F" is used as the object in a great many of the diagrams because it shows quickly whether the image of this letter or object is upright, inverted, or reverted.

## Section II

### REFLECTION

#### 7. REFLECTION FROM A PLANE MIRROR.

a. A plane mirror is a flat polished surface used to reflect light. If a beam of light is permitted to enter a darkened room, and a plane mirror is held so that the beam will strike the mirror, the beam will be reflected. By shifting the mirror, the beam can be reflected to almost any part of the room.

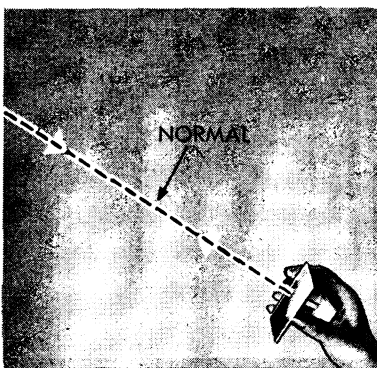
b. If the mirror is shifted so that it is exactly at right angles to the beam, the reflected beam will be directed back along the path of the incoming beam (fig. 13). If the mirror is shifted at an angle from the beam, the reflected beam will be shifted at an angle from the incoming beam that is twice as great as the angle to which the mirror is shifted (fig. 14). For example, if the mirror is held at an angle of 45 degrees to the incoming beam, the reflected beam will be projected at an angle of 90 degrees to the incoming beam.

c. These simple experiments illustrate one of the dependable forms of action of light. Because any kind of light, on being reflected by a smooth, polished surface, acts in the same manner, light can be reflected precisely to the point where it is required. This action of light is put to use in many types of fire control instruments.

d. The ray of light which strikes the surface is called the *incident ray* (fig. 15). The ray which is reflected is termed the *reflected ray*. An imaginary line at right angles to the surface is called the *normal* or *perpendicular*. The angle between the incident ray and the normal is the *angle of incidence*, while the angle between the reflected ray and the normal is the *angle of reflection*.

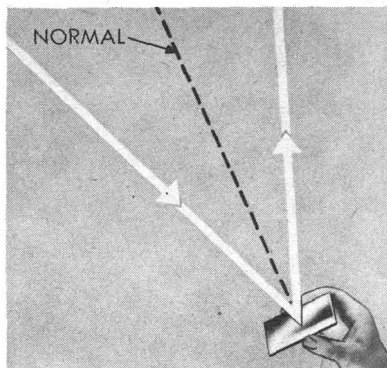
#### 8. LAW OF REFLECTION.

a. The law of reflection is as follows: The angle of reflection is equal to the angle of incidence, and lies on the opposite side of the normal.



RA PD 30216

Figure 13 — Beam of Light Reflected Back on Own Path



RA PD 30217

Figure 14 — Beam of Light Reflected at an Angle

b. Diagrams A, B, C, and D in figure 16 show light rays incident upon plane mirrors at successively smaller angles. By applying the law of reflection, it can be seen that in all such cases of reflection, the angle of reflection can be plotted as long as the angle of incidence is known, or vice versa.

## 9. IRREGULAR REFLECTION OR DIFFUSION.

a. There are two main types of reflection, regular and irregular.

b. Regular reflection occurs when light strikes a smooth surface and is reflected in a concentrated manner (fig. 17).

c. If a beam of light strikes a rough surface, such as a sheet of unglazed paper or ground glass, the light is not reflected regularly but is scattered in all directions (fig. 18). The result is that the entire object may reflect light of the same intensity over its whole surface. This is called irregular reflection or diffusion.

d. The direction in which any single ray of light will be reflected can be plotted by erecting a perpendicular or normal at the point of impact and applying the law of reflection (fig. 18). Any rough surface can be regarded as an infinite number of elementary plane surfaces, at each of which the law of reflection holds true.

e. Light is reflected by diffusion from nearly every object which is seen. Because the light falling on such an object is scattered in all directions, the object is made visible, generally, when viewed from any direction. Skin, fur, and even the dull surface of "OD" lacquer reflect light in a diffused manner. The glossy finish of a new automobile or the bright finish of a polished casting reflects light by regular reflection.

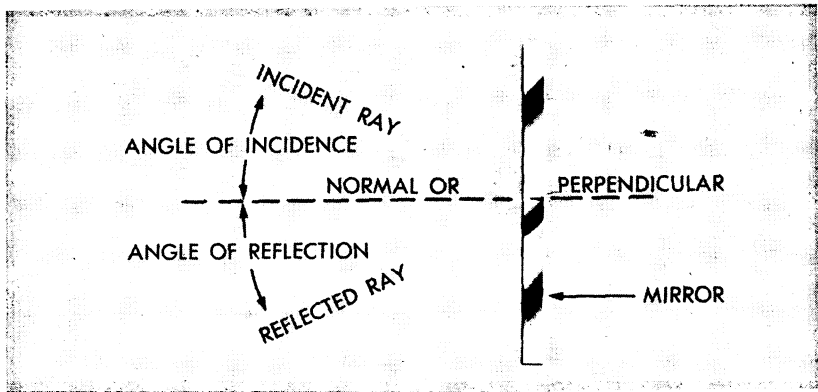


Figure 15 — Terms Used With Reference to Reflected Light

10. REFLECTION FROM CONVEX MIRROR.

- a. The law of reflection holds true for all surfaces, whether convex, concave, or plane. The action of various curved surfaces in directing the course of the reflected light will vary according to the amount of curvature of the reflecting surface and the distance of the light source from the reflecting surface.
- b. Assume that light from an infinite (distant) source, such as the sun, strikes a convex mirror (fig. 19). It will be found that the rays will be deflected in a divergent manner. The reason for this can be determined by plotting the angles of reflection of individual rays in relation to their angles of incidence and the normals for each ray. In this case, the normal for each ray is an imaginary line drawn from the center of curvature of the mirror to the point of incidence of the ray. The angle of reflection will be equal to the angle of incidence of each ray.
- c. If the light source is at a finite distance, or close to the mirror, the rays will be reflected in a divergent manner also. Such rays will

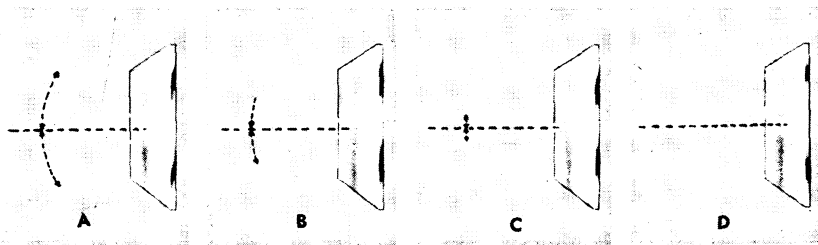
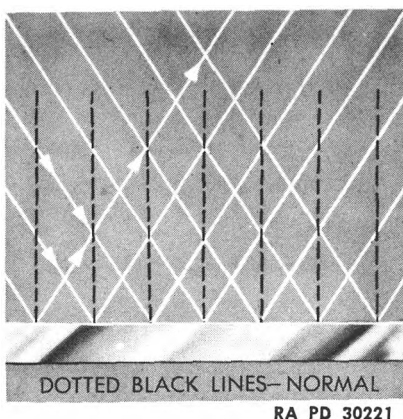
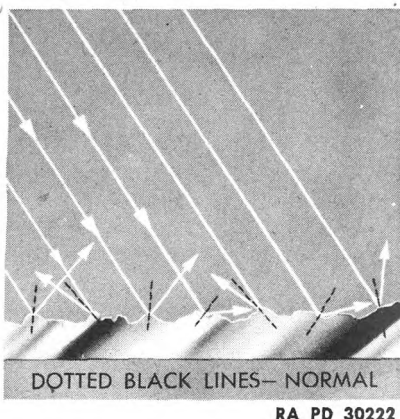


Figure 16 — Reflection From a Plane Mirror

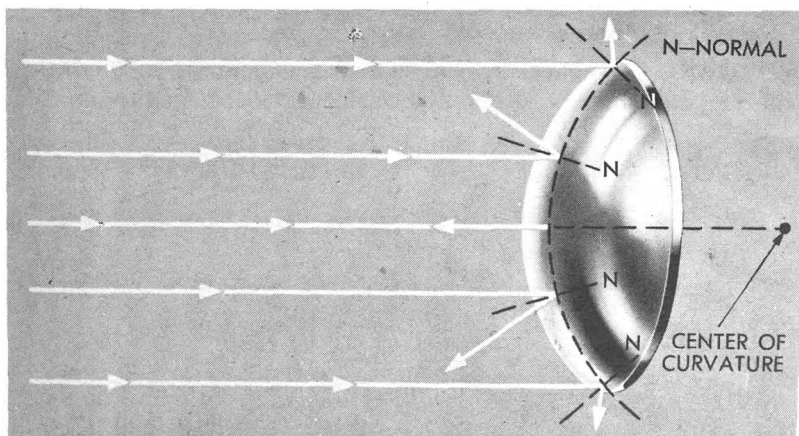


*Properties of Light***Figure 17 — Regular Reflection****Figure 18 — Irregular Reflection**

be reflected at different angles than would be the case if all of them struck the mirror as parallel rays.

## 11. REFLECTION FROM CONCAVE MIRROR.

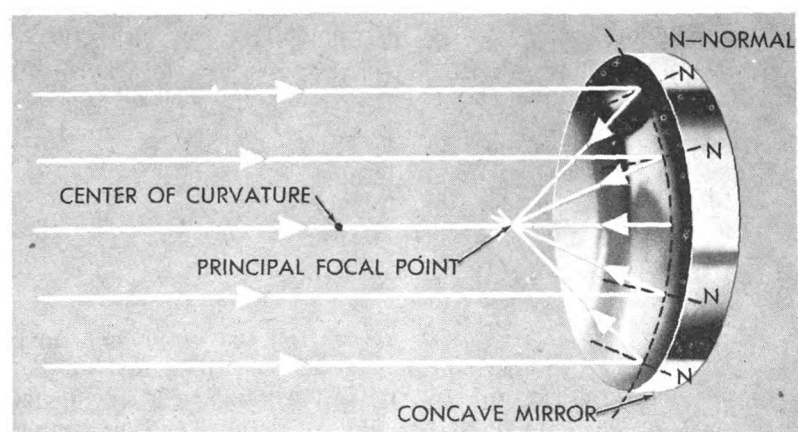
a. The law of reflection is again applied to locate the path of the reflected rays when plotting the reflection from a concave mirror. In this instance, the center of curvature of the mirror is in front of the mirror (fig. 20). Imaginary lines are run from this center to the points of incidence of the incidence rays to indicate the normals of individual rays. When this has been done, the reflected rays can be plotted so that each forms an angle of reflection which will be equal to the angle of incidence of the corresponding ray.



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**Figure 19 — Reflection From Convex Mirror, Infinite Source**

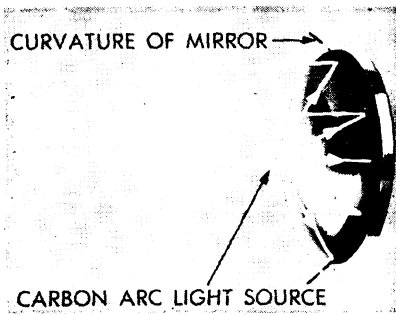
Properties of Light



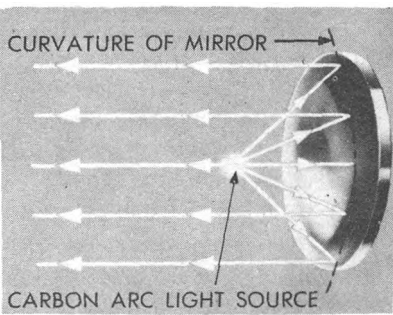
RA PD 30225

Figure 20 — Reflection From Concave Mirror

- b. It will be noted that the rays are converging after reflection and that they intersect at a point halfway between the center of curvature and the surface of the mirror. This point is known as the principal focal point of the mirror. This point of principal focus is always one-half of the distance from the center of curvature to the surface of a concave mirror, provided the mirror is a true portion of a circle. After passing through the focal point, the light will diverge.
- c. If a luminous source is located at the principal point of focus, the rays will be parallel after reflection. This is true only if the curvature is very slight. Actually, the rays will have a slight convergence, especially those which are reflected from near the edges of the mirror (fig. 21). For this reason, if it is desired to have parallel rays after reflection, a parabolic mirror is used.
- d. With a parabolic mirror, light rays emanating from the focal point are parallel after reflection, since this is the principal focal point



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Figure 21 — Projection by Spherical Mirror      Figure 22 — Projection by Parabolic Mirror

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of the mirror. The source of light, which may be a filament or an arc is accurately located in the principal point of focus. All rays are reflected parallel to each other. This allows a long, powerful beam of light to be formed which diverges very slightly, if at all.

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**Section III****REFRACTION****12. REFRACTION THROUGH A GLASS PLATE.**

a. What happens when light is refracted can be understood by imagining a beam of light, indicated by a broad "light ray" or "light beam" (fig. 23), passing in "slow motion" through a sheet of glass. Both plane surfaces of this glass plate are parallel and air contacts both surfaces. The glass and the air are transparent but the glass is denser than the air. Light travels approximately one-third slower in glass than in air.

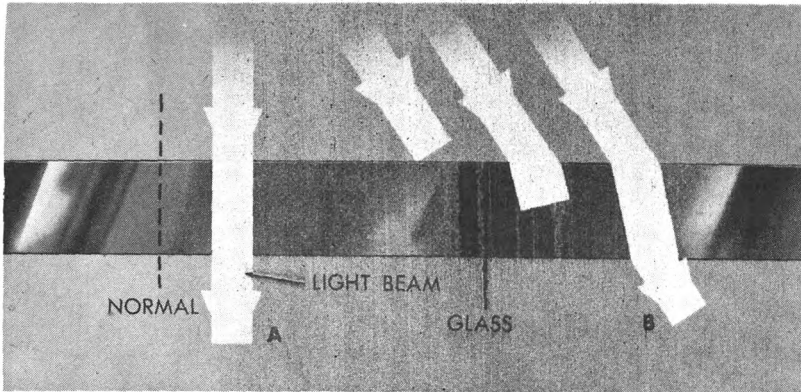
b. If the beam strikes the glass directly at right angles (or the normal), the light is not bent or refracted (A, fig. 23). Its speed is slowed down upon encountering the denser medium, but as the entire front strikes the glass at the same instant, its path is not deviated but continues through the medium in a straight line. Upon reaching the other surface of the glass, the beam enters the lighter medium, air, and resumes its faster and normal speed in air.

c. If this beam of light strikes the glass at an angle, one of the edges arrives at the surface an instant before the other edge does. The edge of the front arriving at the glass first is slowed down upon entering the denser medium and is deviated *toward* the normal (B, fig. 23). When the other edge enters the glass, it is slowed down and deviated in the same manner. The effect is to swing the entire beam toward the normal. This bending of light is termed *refraction*. The light follows its new course in a direct line when the density of the medium is constant.

d. Upon leaving the other surface of the glass plate, the light is again refracted or bent (B, fig. 23). The edge which entered the glass first traverses the glass first. Upon leaving the denser medium and entering the lighter medium (air), its path is deviated again, this time *away from* the normal. This action is duplicated when the other edge leaves the glass. The effect is to swing the entire beam away from the normal.

e. Refraction may be visually demonstrated by placing the straight edge of a sheet of paper at an angle under the edge of a glass plate held vertically (fig. 24). The straight edge of the sheet of paper will appear to have a jog in it directly under the edge of the glass plate. That portion of the paper on the other side of the glass

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**Figure 23 — Path of Beam of Light Through Sheet of Glass**

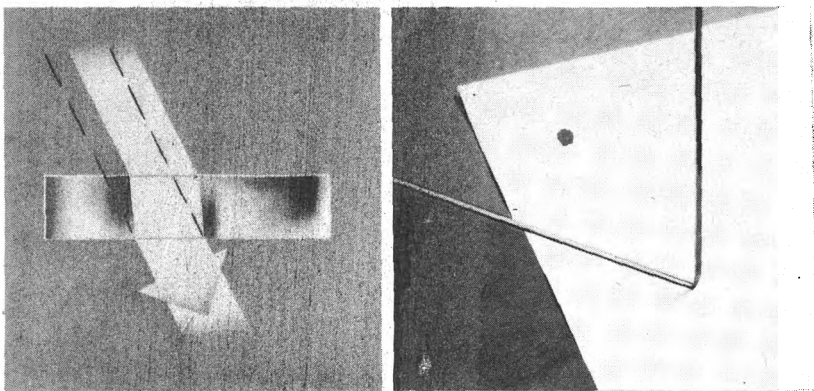
will appear to be displaced due to refraction. As the sheet of paper is moved to change the angle of its straight edge, the amount of refraction will be increased or decreased. If the straight edge of the paper is viewed at right angles to the surface of the glass, there will be no refraction.

### 13. LAW OF REFRACTION.

a. The law of refraction can be stated as follows: In passing from a medium of lesser density to one of greater density, the path of light is deviated *toward* the normal. In passing from a medium of greater density to a medium of lesser density, the path of light is deviated *away from* the normal (fig. 25).

b. The greater the angle at which the light strikes the medium, and the greater the difference in density between the two mediums, the greater the bending. If the faces of the medium are parallel, the bending at the two faces is always the same, so that the beam which leaves the denser medium is parallel to the incident beam (fig. 24).

c. The ray which strikes the surface is called the *incident ray* (fig. 25). The ray entering the second medium is the *refracted ray*. The ray leaving the second medium is the *emergent ray*. An imaginary line at right angles to the surface of the medium at the point where the incident ray strikes the surface is termed the *normal* or *perpendicular*. The angle between the incident ray and the normal is the *angle of incidence*. The angle between the refracted ray and an extension of the incident ray is termed the *angle of deviation*. It is the angle through which the refracted ray is bent from its normal

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**Figure 24 — Effects of Refraction**

path by the density of the refracting medium. The angle formed by the refracted ray with the normal is called the *angle of refraction*.

d. The angle of refraction depends on the relative density of the two mediums, as well as on the angle of incidence. An equation, known as Snell's law, may be used to determine the angle of refraction ( $r$ ) if the angle of incidence ( $i$ ) and the index of refraction (par. 14 b) of each medium are known. This equation is:

$$\frac{\sin i}{\sin r} = n$$

where  $n$  is the quotient of the indices of refraction of the two mediums. If one of the mediums is air,  $n$  is the index of refraction of the second medium.

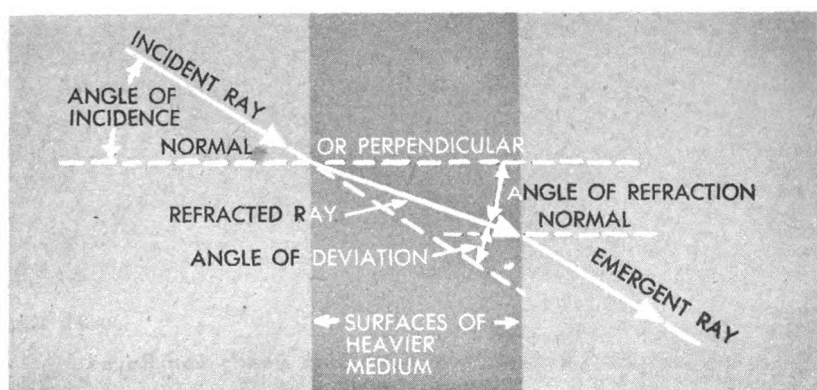
**14. INDEX OF REFRACTION.**

a. Light travels through substances of different densities with greatly varying velocities. For example, the speed of light in air is approximately 186,000 miles per second; in ordinary glass, it is approximately 120,000 miles per second.

b. The ratio between the speed of light in air and the speed of light in a second medium is known as the *index of refraction*. The index of refraction is usually indicated by the letter  $n$  and is determined by dividing the speed of light in a vacuum by the speed of light in the particular medium.

c. The following table contains the index of refraction of each of a number of substances pertaining to optics. NOTE: For most computations, the index of air is considered to be unity (1.000).

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**Figure 25 — Terms Used With Reference to Refracted Light**

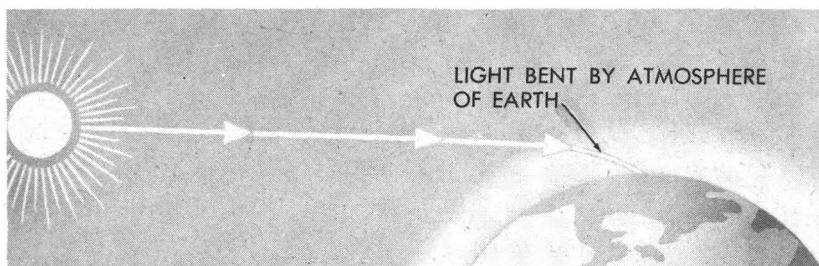
|                                 |          |
|---------------------------------|----------|
| Vacuum .....                    | 1.000000 |
| Air .....                       | 1.000292 |
| Water .....                     | 1.333    |
| Ordinary crown glass .....      | 1.516    |
| Boro-silicate crown glass ..... | 1.524    |
| Canada balsam .....             | 1.530    |
| Gelatin .....                   | 1.530    |
| Light flint glass .....         | 1.571    |
| Medium flint glass .....        | 1.627    |
| Dense flint glass .....         | 1.754    |
| Densest flint glass .....       | 1.963    |

## 15. ATMOSPHERIC REFRACTION.

a. At a surface separating two media of different indices of refraction, the direction of the path of light changes abruptly when passing through the surface. If the index of refraction of a single medium changes gradually as the light proceeds from point to point, the path of the light will also change gradually and will be curved rather than in a straight line.

b. Although air at its densest has a refractive index of only 1.000292, this is sufficient to bend light rays from the sun toward the earth when these rays strike the atmosphere at an angle (fig. 26). The earth's atmosphere is a medium which becomes denser toward the surface of the earth. The result is that a ray of light traveling through the atmosphere toward the earth at an angle does not travel in a straight line but is refracted and follows a curved path. From points near the horizon, the bending of light is so great that the setting sun is seen after it is completely below the horizon (fig. 27).

c. The bending of the paths of rays of light in a horizontal plane is not due to any systematic variation of the refractive index. This

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**Figure 26 — Atmospheric Refraction Bends Sun Rays**

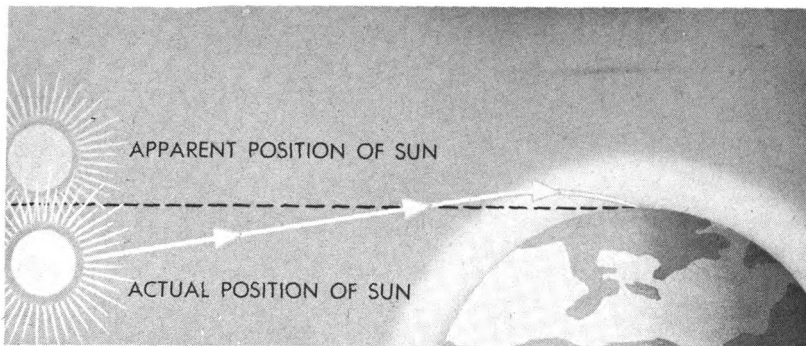
variation is generally so small that it can be neglected in many types of observation made with fire control instruments. In very careful surveys of large areas, this effect is eliminated by repeating the observations on different days and under different conditions. In the aiming of guns over wide expanses of water, as must be done by coast artillery, a special instrument, the depression position finder, takes atmospheric refraction as well as other conditions into consideration.

d. Over large areas of heated sand or over water, conditions are such as to produce strata or layers of air differing greatly in temperature and refractive index. Under such conditions, erect or inverted and sometimes much distorted images are formed which can be seen from a great distance. These images are known as *mirages*.

e. On a hot day, the columns of heated air rising from the earth are optically different from the surrounding air, and paths of light are irregularly reflected. The air is turbulent and conditions under which observations are made are changing all the time. Consequently, an object viewed through such layers of air appears to be in motion about a mean position. In such cases, the air is said to be "boiling" or the image is "dancing," due to "heat waves." This condition is particularly detrimental when a high-power telescope is employed. Under such conditions it is usually impossible to use an instrument of more than 20 power.

**16. REFRACTION THROUGH A TRIANGULAR GLASS PRISM.**

a. Refraction through a triangular glass prism differs from refraction through a sheet of glass with parallel surfaces because the light which penetrates the base or thicker part of the prism must travel longer and at less speed in a denser medium than the light passing through the apex or thinner part of the prism. Rays of light emerging from a plate of glass with parallel surfaces always travel in a parallel direction with the incident rays; rays emerging from a prism always travel at different angles from the incident rays.

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**Figure 27 — Sun Below Horizon Seen by Refracted Light**

b. The laws of refraction apply to prisms just as they do to plates of glass with parallel surfaces. These laws may be applied to plot the paths of light through any prism.

c. When a ray of light strikes the surface of a prism, the refracted ray (fig. 28) is bent toward the normal according to the law of refraction. The refracted ray is bent away from the normal on leaving the prism. Thus, the path of the ray is deviated at the first surface of the prism and then further deviated at the second surface. In both cases, the ray is bent toward the thickest part of the prism.

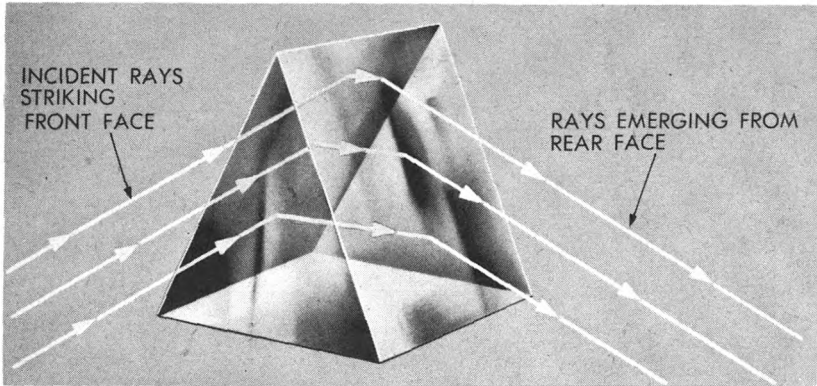
**17. REFRACTION THROUGH LENSES.**

a. **Convergent Lens.** If two prisms are arranged base to base (fig. 29), rays of light striking the front surfaces will pass through the prisms. The rays emerging from one prism will cross the emergent rays of the other prism.

b. If the two prisms are cut in semicircular form, their surfaces made spherical, and the two bases cemented together, the result will be an optical element known as a *convergent lens*. (All convergent lenses are thicker at the center than at the edges.) When rays of light strike the front surfaces of a convergent lens (fig. 30), all rays pass through the lens and converge to a single point where they cross (color and other aberrations are disregarded at this time). Such a lens may be thought of as consisting of an infinite number of prisms arranged so that each direct light rays to a single point. The lens bends the rays as a prism does, but, unlike a prism, it brings them to a point.

c. Myriads of rays may be considered to come from every point of light on an object. Consider the refraction of three such rays from a point of light passing through a convergent lens (fig. 31) to intersect at a point on the other side of the lens. On the basis



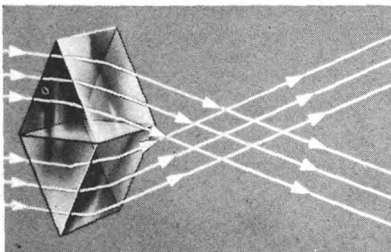


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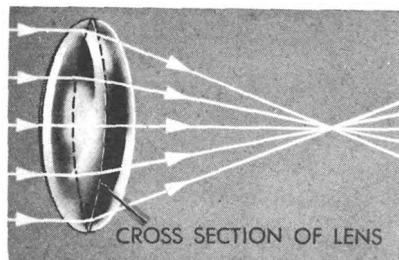
**Figure 28 — Path of Light Ray Through Prism**

that a lens bends the rays as a prism does, rays passing through the upper and lower portions of the lens would be bent toward the thickest part of the lens upon striking the first surface, and bent again toward the thickest part in emerging. As the result, they would converge on the other side. A straight line drawn through the center of the two spherical surfaces is termed the *axis* of the lens. A central or axial ray would not be deviated because it would strike the surfaces of the lens at the normal. Such a ray would join the outer rays at their convergent point.

d. The laws of refraction may be applied to plot the path of any ray through any lens. A ray entering a lens will bend toward the normal of the lens at that point (fig. 32). The normal of an incident ray at any point on a lens is an imaginary line at right angles to the surface of the lens at the point where the ray enters. As the refracted ray leaves the lens as the emergent ray, it is bent away from its

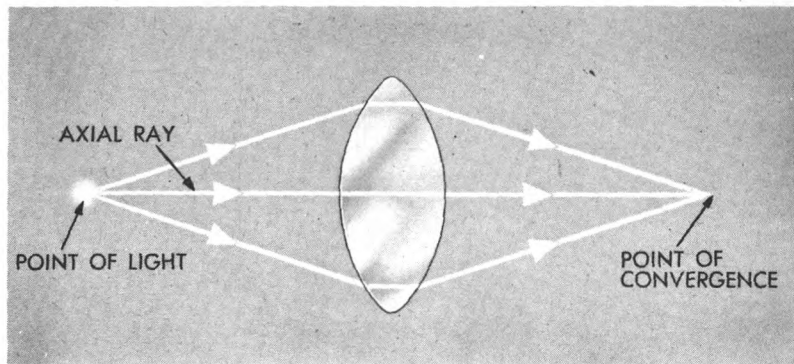


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**Figure 29 — Deviation of Rays by Two Prisms, Base to Base**

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**Figure 30 — Deviation of Rays by Convergent Lens**

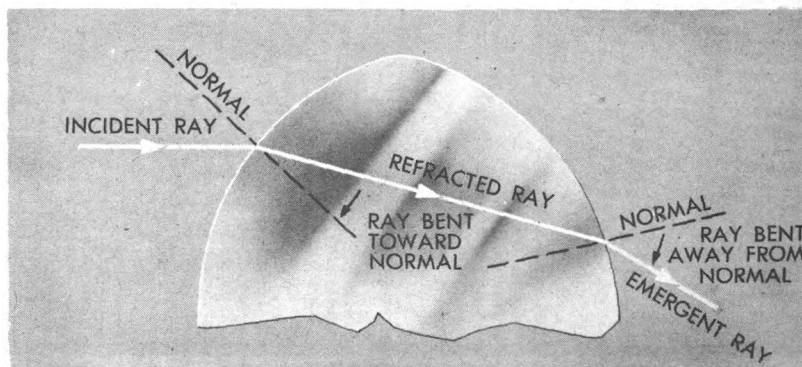


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**Figure 31 — Paths of Rays of Light Through Convergent Lens**

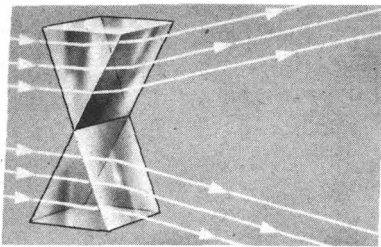
normal. The normal of any emergent ray is an imaginary line at right angles to the surface of the lens at the point where the ray emerges from the lens.

e. **Divergent Lens.** A lens of a different type can be approximated by placing two prisms apex to apex (fig. 33). If rays of light strike the front surfaces of the prisms, the rays will pass through and, in accordance with the law of refraction, those passing through the upper prism will travel upward, while those passing through the lower prism will travel downward. Now assume that the front and rear surfaces of this pair of prisms have been rendered spherical and

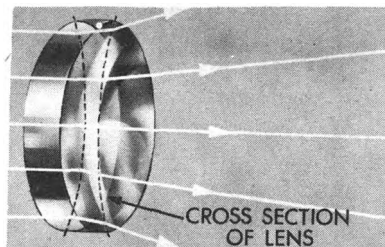


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**Figure 32 — Law of Refraction Applied to Lens**

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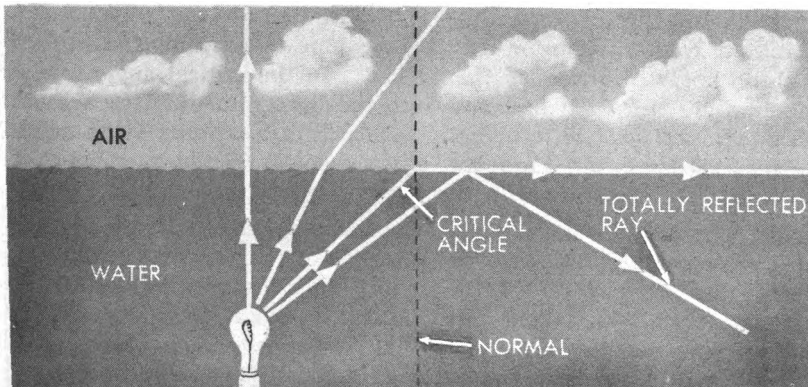
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**Figure 33 — Deviation of Rays by Two Prisms, Apex to Apex****Figure 34 — Deviation of Rays by Divergent Lens**

that the two prisms have been converted into a lens (fig. 34). All rays of light except the axial ray passing through this lens would spread out or diverge, but instead of splitting in two at the axis would diverge evenly in a spherical manner. This type of lens is known as a *divergent lens*. (All divergent lenses are thicker at the edges than at the center.)

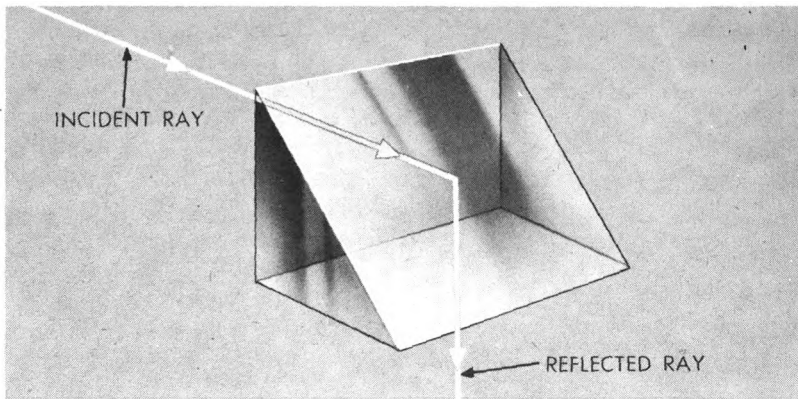
**18. TOTAL INTERNAL REFLECTION AND CRITICAL ANGLE.**

a. When light passing from air into a more dense medium, such as glass, strikes the boundary surface, it is refracted. This occurs regardless of the incident angle. However, when light attempting to leave a more dense medium for a less dense medium strikes the boundary surface, it may be reflected, rather than refracted, even though both mediums are perfectly transparent. This is known as *total internal reflection* and occurs when the incident angle exceeds



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**Figure 35 — Angles of Light Rays From an Underwater Source**

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**Figure 36 — Total Internal Reflection in Prism**

a certain *critical angle*. The critical angle depends upon the density of the medium. Critical angles for various substances are listed in paragraph 19.

b. The total internal reflection of light can be illustrated by following the rays from a light source under water. Water has a critical angle of 48 degrees 36 minutes. Rays of light from such a source would be incident at various angles on the surface separating the water and air (fig. 35). As the angle of incidence of the light rays increases, the deviation of the refracted rays becomes proportionately greater. A point is reached where an incident ray is deviated to such an extent that it travels along the surface of the water and does not emerge into the air. The angle formed by this incident ray and the normal is the critical angle of the medium.

c. All rays traveling in a dense medium and striking the surface with an angle of incidence that is less than the critical angle of the medium are *refracted* and pass into the lighter medium in accordance with the laws of refraction. All such rays striking at an angle of incidence greater than the critical angle of the medium are *reflected* in accordance with the laws of reflection.

d. The critical angle has a practical application in the design of prisms used in fire control instruments. In such instruments, it is quite often necessary to change the course of the path of light. This deviation could be accomplished by mirrors but the prisms used perform the task more satisfactorily. When prisms are employed that have angles greater than the critical angle of the substance of which they are made, their reflecting surfaces do not require silvering, yet these surfaces appear to be silvered when one looks into such a prism.

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e. Consider a prism with two faces at right angles and a back or hypotenuse at a 45-degree angle (fig. 36). An incident ray, striking one of the right-angle faces at the normal, passes into the prism without refraction or deviation until it hits the boundary of the medium (back of the prism). Since the angle of the back is 45 degrees and the critical angle of the glass of the prism is 42 degrees, the ray cannot pass through the back surface of the prism. Instead, it is totally reflected. Inasmuch as the angle of incidence between the incident ray and the normal (at the back surface) is 45 degrees, the angle of reflection would be the same because these angles are always equal. The result is that the ray is reflected a total of 90 degrees, strikes the surface of the other right-angle face of the prism at the normal, and passes out of the prism without further deviation.

**19. CRITICAL ANGLES OF VARIOUS SUBSTANCES.**

a. The critical angles for various substances, when the external medium is air, are as follows:

|                   |         |
|-------------------|---------|
| Water .....       | 48° 36' |
| Crown glass ..... | 43° 8'  |
| Quartz .....      | 40° 22' |
| Flint glass ..... | 37° 34' |
| Diamond .....     | 24° 26' |

b. The small critical angle of diamond accounts for the brilliance of a well-cut diamond. It is due to the total internal reflection of light which occurs for a greater variety of angles than in any other substance. The light entering the diamond is totally reflected back and forth a number of times before emerging, producing bright multiple reflections.

**Section IV****IMAGE FORMATION****20. GENERAL.**

a. In considering the principles of the formation of images by lenses, for simplicity of explanation it will be assumed that perfect single lenses are used.

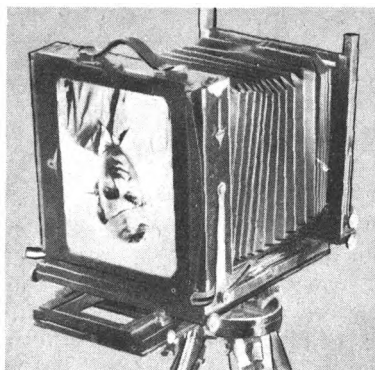
**21. CLASSIFICATION OF IMAGES.**

a. **Virtual and Real Images.** Two types of images are produced by optical elements, virtual images and real images.

(1) **VIRTUAL IMAGES.** A virtual image is so called because it has no objective or real existence. It exists only in the mind and cannot be thrown upon a screen because it is apparent only to the eyes of the observer. A familiar example is the virtual image formed by a mirror. The image of the person looking into the mirror appears

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Figure 37 — Virtual Image Reflected by Plane Mirror      Figure 38 — Real Image Formed on Ground Glass of Camera

to be on the other side of the mirror (fig. 37). No trace of the image can be seen on the back of the mirror.

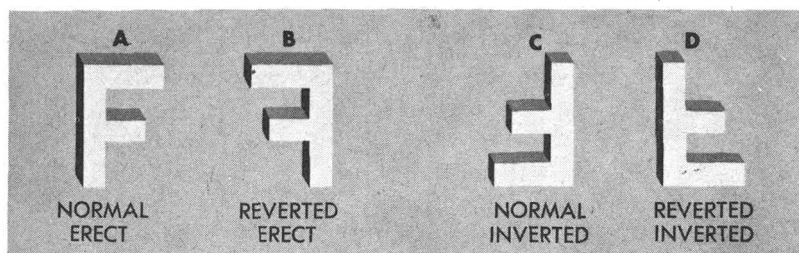
(2) **REAL IMAGES.** A real image actually exists. It can be thrown upon a screen. The lenses of the human eye and the camera form real images. The real image formed by a camera can be seen on the ground glass (fig. 38).

**b. Erect, Inverted, Normal, and Reverted Images.** When an image is reflected or refracted by optical elements, the parts of the object are seen as being transposed horizontally, vertically, or both. This is illustrated by what happens to the letter "F" (fig. 39).

(1) An image, regardless of size, that shows the face of an object unchanged is said to be *normal* and *erect* (fig. 39A). When the object is seen as horizontally transposed through 180 degrees, it is termed *reverted* and *erect* (B, fig. 39). Reversion is the effect seen in a mirror where the image is reversed so that the right side of the object becomes the left side of the image (fig. 37).

(2) The image of an object with its face unchanged but upside down is termed *normal* and *inverted* (C, fig. 39). If it appears turned from left to right as well as upside down, it is said to be *reverted* and *inverted* (D, fig. 39). Inversion is the effect seen on the ground glass of a camera (fig. 38). Such an image is normal and inverted.

**c.** The most satisfactory method of visualizing the positions in which an image may be transposed is by cutting a letter "F" out of paper and marking the face and reverse sides "NORMAL" and "REVERSED," respectively. If the normal erect letter (A, fig. 39) is inverted bottom side up without turning it over, it will appear as in C, figure 39. If it is then turned over or "inverted" sideways, it will appear reverted and inverted (D, fig. 39).



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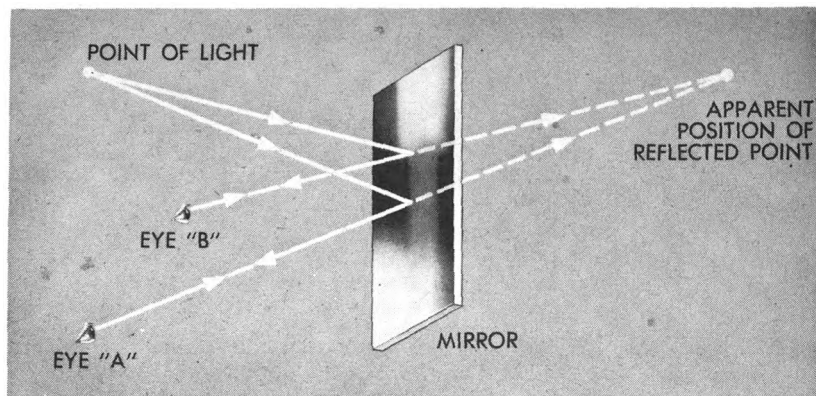
**Figure 39 — Letter "F" as Reflected or Refracted by Optical Elements****22. IMAGE REFLECTION BY PLANE MIRROR.**

a. When the image of an object is seen in a mirror, it appears to be located at a distance behind the reflecting surface equal to the distance of the object from the front of the mirror. The image is erect and reverted, as are all single reflections from plane mirrors.

b. In a dark room, the image of a tiny point of light is seen reflected at an angle from a mirror in the middle of the floor (fig. 40). The source of light as viewed in the mirror appears to the observer to be located behind the mirror and on the other side of the room from which it actually is. The observer sees along the path of the reflected ray to the point where the incident ray is reflected by the mirror. His line of sight is extended in a direct line through and beyond the mirror. The apparent position of the light is located directly across the room from the light source, and at the same distance behind the mirror as the light source is in front of the mirror (EYE "A," fig. 40).

c. Regardless of where the observer stands, if he can see the reflection of the point of light in the mirror, its apparent position is unchanged. This holds true whether he walks forward along his line of sight without affecting the angles of incidence and reflection of the ray, or steps to either side, changing his line of sight and the angles of incidence and reflection (EYE "B," fig. 40). It is the object (source of light) that is reflected, and the apparent position of its reflection is changed only when the position of the object is changed.

d. Now, assume that the light source is replaced by a cut-out letter "F" covered with luminous paint (fig. 41). Light from every point on the letter sends out incident rays which are reflected by the mirror. Each incident ray and reflected ray obeys the laws of reflection and their paths can be plotted accordingly. As the result, the entire image formed by the combination of this infinite number of images of individual points of light, is reflected to the eye of the observer. The observer, looking along the paths of the reflected

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**Figure 40 — Reflection of Point of Light in Mirror**

rays, sees the image formed by the points of light. The image he sees appears to be in back of the mirror as an erect, reverted image (fig. 41).

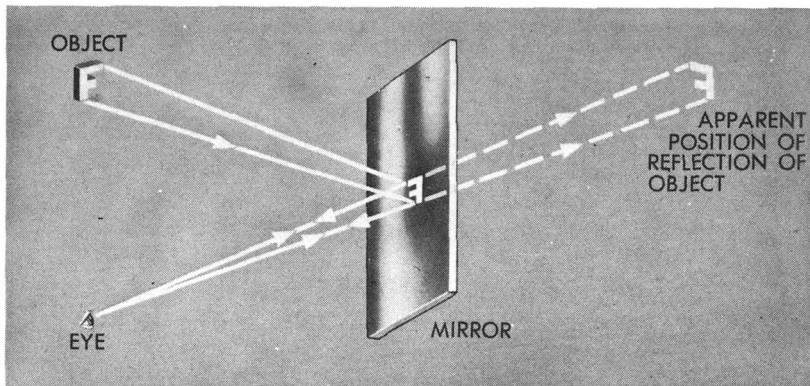
### 23. IMAGE TRANSMISSION BY MIRROR AND PRISM.

a. **Image Transmission by Mirror.** Image transmission by mirror is simply image reflection from one or more plane mirrors put to practical use. The mirror is mounted so that it will transmit the image that is focused upon it to whatever point is desired. If this cannot be accomplished with a single mirror, a second mirror is placed to catch the reflection from the first mirror and transmit the image again.

b. Consider two mirrors placed at 90-degree angles to one another. The image of the letter "F" is reflected onto the reflecting surface of one of the mirrors (fig. 42). Light rays from every point on the image of the letter "F" are reflected by the first mirror, according to the laws of reflection, to the second mirror, and reflected again, this time parallel to the original paths of the light rays. The image will have been reflected a total of 180 degrees, and will be reverted in the plane in which the reflection takes place.

c. **Image Transmission by Prism.** Image transmission by prism is brought about in practically the same manner as an image is transmitted by one or more plane mirrors (fig. 43). Actually, the reflecting surfaces of a prism are plane mirrors. These surfaces are silvered when the angle at which the light strikes is less than the critical angle (par. 18) of the material from which the prism is made; the surfaces require no reflecting agent when their angle is greater than the critical angle.



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**Figure 41 — Reflection of Letter "F" in Mirror**

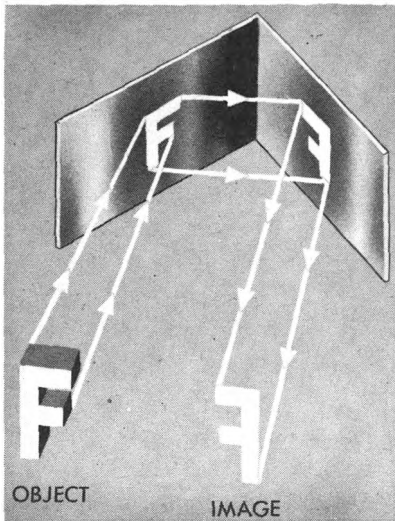
d. **Comparison.** When mirrors are used, the image is reflected through air; when a prism is used, the image is reflected through glass. While being transmitted through glass, the paths of the rays of light are not deviated because they travel in a medium of constant density. These paths are not deviated upon entering or leaving the glass of the prism, provided the light rays strike the surface of the glass at the normal.

**24. FOCAL LENGTH AND FOCAL PLANE.**

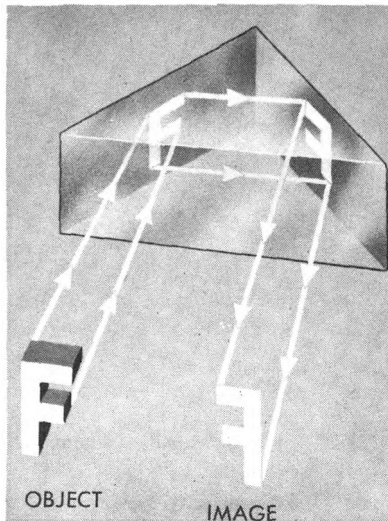
a. **Focal Point of Convergent Lens.** When light strikes and passes through a convergent lens, the rays from a point of light intersect at a point on the opposite side of the lens. The point at which the rays intersect is termed the *focal point*.

b. The focal point of a lens will vary in relation to the distance of the object. If a sheet of ground glass or thin paper is placed across the back of a camera, or held in back of a lens at a distance that will permit the lens to focus the images of objects on the glass or paper, images of all distant objects may be brought into sharp focus at one time, regardless of their distance. An object very close to the lens will be out of focus. The ground glass or paper will have to be moved backward to bring such an object into sharp focus; then the more distant objects will be out of focus.

c. The focal point where the rays from a distant object intersect is called the *point of principal focus* (fig. 44). The *optical center* of a lens is a point at the center of the thickest part of a converging lens or the thinnest part of a divergent lens. It lies on a straight line connecting all the principal focal points of the lens. Rays of light pass through the optical center without deviation. The distance from the point of principal focus to the optical center of a convergent lens

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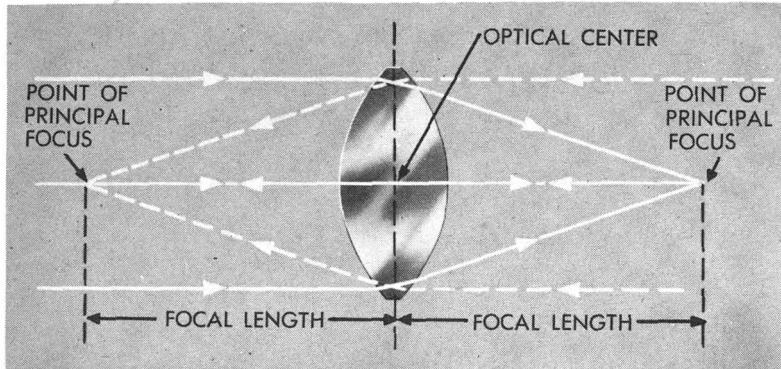
**Figure 42 — Image Transmission by Mirrors    Figure 43 — Image Transmission by Prism**

is the *focal length* of the lens. The thicker the lens in relation to its size, or the steeper the curves of the lens, the shorter its focal length will be.

d. The *focal plane* of the lens (fig. 44) is a thin, flat area at right angles in all directions from the focal point. It is the area that is occupied by the ground glass or paper which might be used to make the image visible. In a camera, the film is placed in the focal plane of the lens. The focal point is the image of a single point of light on the object; the focal plane is the combined image of *all* the points of light on the object.

e. **To Determine Focal Length of Convergent Lens.** A rough calculation of the focal length of a convergent lens can be secured by holding the lens to focus the image of some distant object on a sheet of paper or ground glass. When the image is clear and sharp, this will indicate that the point of principal focus has been reached. Measure the distance from the image to the optical center of the lens.

f. **Focal Length of Divergent Lens.** The point of principal focus and any focal points and focal planes resulting from the nearness of the object to the lens are located on the side of the divergent lens toward the object or light source. The point of principal focus and other focal points are located where the emergent rays would intersect on the axis if they were extended backward as imaginary lines toward the side of the lens on which the light strikes (fig. 45). The distance from the point of principal focus to the optical center of the lens is the focal length.

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**Figure 44 — Focal Lengths of Convergent Lens****25. MAGNIFICATION AND MINIFICATION.**

a. Magnification is the apparent enlargement of the image of the object to the eye of the observer. Common examples are the reading glass and microscope. In a fire control instrument, magnification, by making targets appear larger, makes them appear closer.

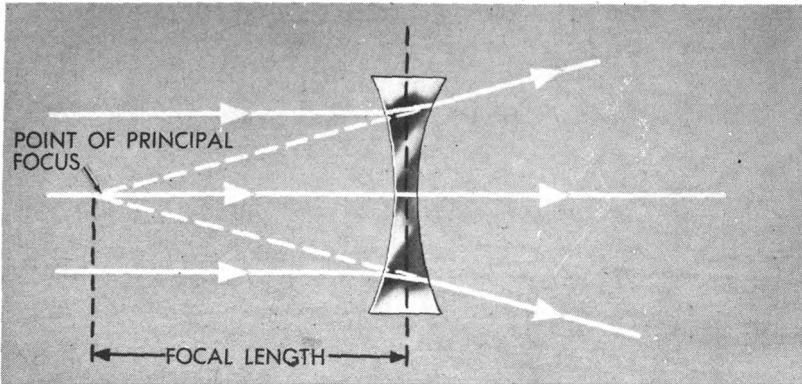
b. Minification is the apparent reduction in the size of the image of the object to the observer. A lens placed in the floor of an airplane to permit observation functions on this principle. It makes objects appear smaller than when viewed with the unaided eye but has the advantage of increasing the field of view. A much larger area may be scanned through the relatively small opening than would be possible if the lens were not used.

c. The degree of magnification of an optical instrument is expressed as the *power* of the instrument, that is, 8-power. An 8-power (8X) telescope will produce an image, the apparent size of which is eight times as high and eight times as wide as the image when viewed by the unaided eye.

d. Military targets can often be seen better with 10-power magnification than with 20-power, due to varying conditions of light. For this reason, some fire control instruments are fitted with means for changing the power of magnification. Certain instruments provide *no* magnification; their primary purpose is to place a reticle in the field of vision.

**26. IMAGE FORMATION BY CONVERGENT LENS.**

a. Images which are formed by convergent lenses may be either real or virtual images. They may be larger or smaller than the objects, depending upon the distance of the object from the lens.

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**Figure 45 — Focal Length of Divergent Lens**

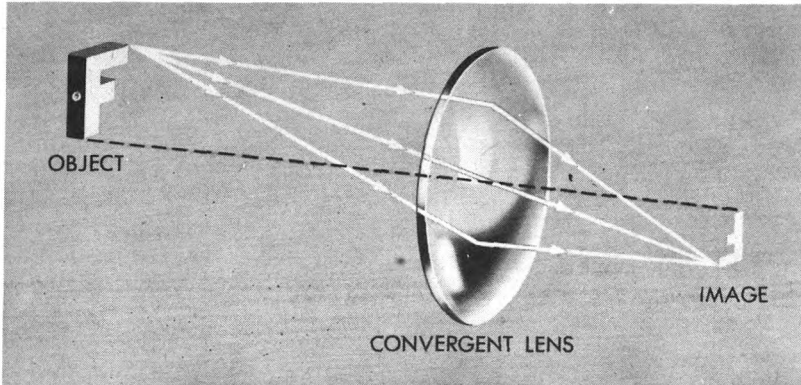
b. Multiple lenses (par. 64) may be used to correct for color and other faults. A theoretically perfect single lens is assumed in this paragraph.

c. To plot the formation of an image by a convergent lens, consider that every point of an object is emitting rays of light which are incident upon the front face of the lens. Three rays from each of two points will be sufficient to indicate the action of the rays and to locate the image (fig. 46).

(1) Assume that one ray from the top of the object will pass through the center of the lens. Since this ray will strike the lens at the normal, its path is not deviated. A second ray from this point of light strikes the lens above the axis, is refracted upon entering and upon leaving the denser medium, and intersects the first ray. A third ray strikes the lens below the axis, is refracted, and intersects the other two rays. The point where the three rays intersect becomes the focal point for the image. The rays form a point of light corresponding to the top of the object on the other side of the lens from the object.

(2) Three similar rays from a point of light at the bottom of the object form a point of light corresponding to the bottom of the object. Every point of light on the object forms its point of light on the image in the same way. As light rays from the upper part of the object form points of light on the lower part of the image, and vice versa, the image is *inverted*. An image formed in this way is *real*.

d. The image of an object located at any distance beyond two focal lengths of the lens is smaller than the object. If the object is at two focal lengths, the image is the same size. If the object is

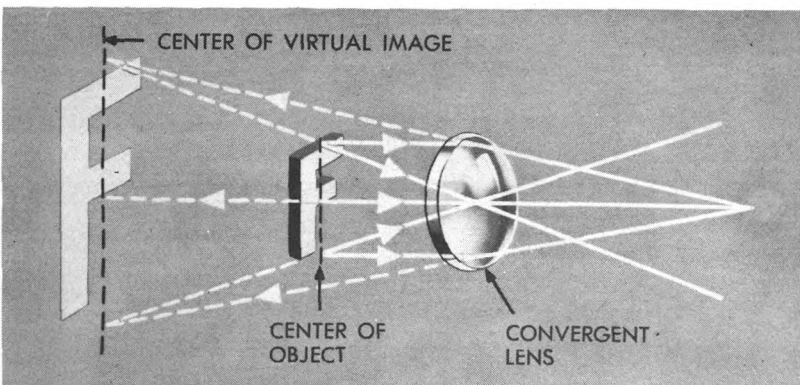
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**Figure 46 — Image Formed by Convergent Lens**

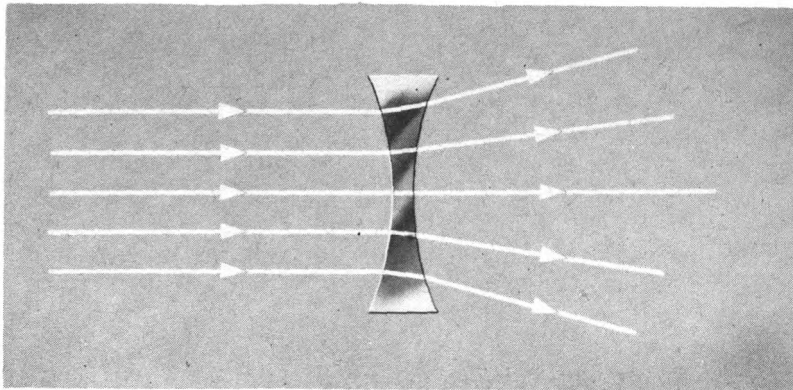
between one and two focal lengths away, the image is magnified. All of these images are inverted and real. If the object is at one focal length, there is no real image because the rays are parallel after refraction; the image is said to be at infinity. This condition, following the principle of reversibility of light paths (par. 3 f) is the reverse of that illustrated in figure 46. Simply change the object for the image and reverse the directions of the arrowheads.

e. **Magnification by Convergent Lens.** If the object is inside one focal length of a convergent lens, the image will be on the same side of the lens as the object, magnified and erect. The image will no longer be real but will be virtual. This is a condition which can be illustrated easily by the use of a reading glass (figs. 47 and 66).



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**Figure 47 — Magnifications by Convergent Lens**

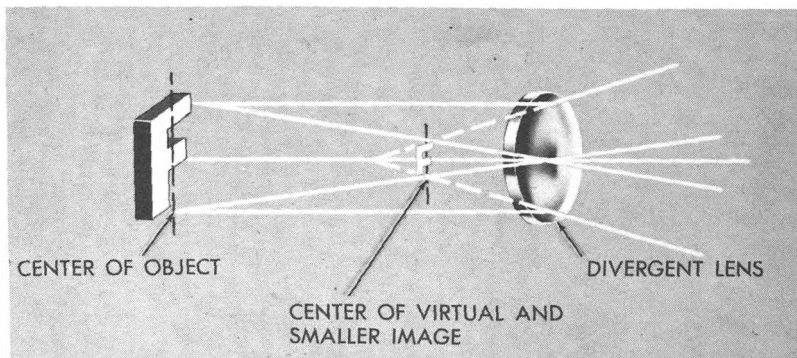
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**Figure 48 — Effect of Parallel Rays on Divergent Lens**

(1) If the observer looks at the object, for example, a portion of a printed page, through a reading glass held close to the type, the printed letters appear larger than they actually are. As he moves the glass away from the type, each letter appears larger and remains clear, provided he moves his eye backward as he moves the glass away from the printed page. At a certain point, the printed letters appear at their largest and clearest. Beyond this point, they become blurred and then inverted. The point where the largest and clearest view of the letters is obtained is just before the focal point of the lens has been reached.

(2) The rays from the object and the reason for the magnification of the image can be plotted at any point in the preceding



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**Figure 49 — Minification by Divergent Lens**

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demonstration (fig. 47). The eye of the observer sees an apparent convergence of the rays from each point of light on the object. These rays form a magnified image of the object which appears to be in back of where it actually is.

## 27. IMAGE FORMATION BY DIVERGENT LENS.

a. Divergent lenses can form only virtual images which are erect and smaller than the object. This holds true regardless of the distance of the object from the lens. Divergent lenses are termed negative because the virtual images formed by them are always on the same side of the lens as the object.

b. Light rays from a distant object strike the face of a divergent lens in parallel rays and, after refraction, are diverted by the lens (fig. 48). In looking along the paths of the rays, the observer sees an apparent intersection of the rays at a point on the same side of the lens as the object. The point where the rays appear to intersect is the focal point. It is a backward continuation of the emergent rays. As the observer looks along the paths of these rays, he sees the virtual image of the object located inside the apparent intersection of these rays (fig. 49). He receives the impression that the image seen on the other side of the lens is smaller than the object.

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## Section V

### COLOR

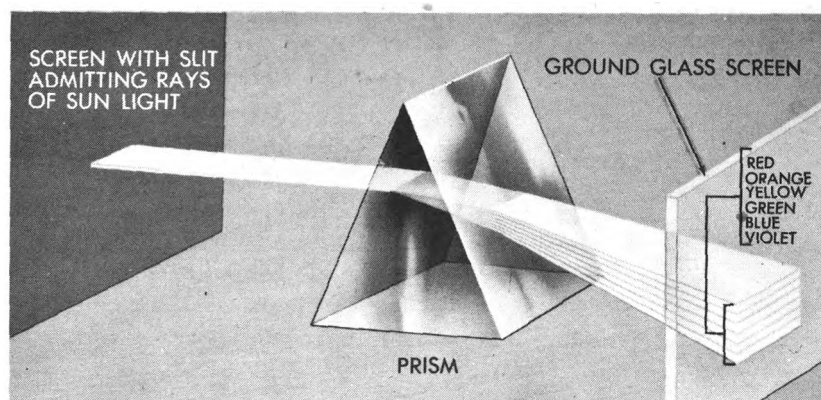
## 28. GENERAL.

a. Ordinary sunlight, or any other "white" light, is a mixture of visible light of all wave lengths. "White" light is, therefore, a mixture of all colors.

b. The amount of deviation of light from its path depends upon the color of the light as well as upon the shape and density of the optical element. Each color of light has its own distinctive wave length and there is a different index of refraction for each color. The unequal deviation of rays of light of various colors—*dispersion*, as it is called—has an important effect on the formation of images and, therefore, upon the design of fire control instruments.

## 29. SEPARATION OF "WHITE" LIGHT.

a. If sunlight is passed through a slit and then through a triangular glass prism, the emergent light is split into a number of refracted rays. If these refracted rays are made to fall upon a screen, they produce a band of colored light called the solar spectrum. The colors

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**Figure 50 – Light Dispersed Into Spectrum by Prism**

of the spectrum are, in order, red, orange, yellow, green, blue, and violet. About 130 distinct hues, including indigo, have been observed.

b. Each color of the spectrum represents light vibrating at a different frequency or wave length. The shorter the wave length, the more the rays are bent upon being refracted. Red light has the longest wave length (fig. 50); violet, the shortest. Red rays are bent the least; violet, the most; the rays of other colors are interspaced accordingly.

c. Glass of various densities disperses light to different degrees. A prism of flint glass disperses the rays of different color more than the less dense crown glass. A lens would also separate light because a lens may be considered as an infinite number of prisms. The properties of different kinds of glass are employed to neutralize the dispersion of the rays of colored light and to neutralize their tendencies to form different focal points when refracted through lenses and prisms (par. 41).

d. The principle of dispersion is put to practical use in a scientific instrument known as the *spectroscope*. This instrument is especially designed to disperse light coming from an incandescent source. Since any element upon being heated to a point of incandescence emits light of a frequency unique to that element, the spectrum of an incandescent solid can be used to show of what that solid is composed. By the use of the spectroscope, helium was discovered in the atmosphere of the sun before it was discovered on earth.

e. An instrument similar to the spectroscope but fitted with a camera permits the photographing of spectra. The photographic records made by this instrument are called *spectrographs*. This instrument is also used to measure refractive indices and is extremely accurate.



**30. SELECTIVE REFLECTION AND ABSORPTION.**

a. Objects derive their color from the selective reflection and selective absorption of light. If an object reflects the greatest percentage of the light striking it, the object appears white. If it absorbs the greatest percentage of light, it appears black. The surfaces of most objects absorb light of certain frequencies and reflect light of other frequencies. The colors of these surfaces are determined by the frequencies they reflect. This is known as *selective reflection*.

b. An object appears to be of a color because it absorbs light of certain wave lengths and reflects others striking it. In sunlight, it may appear to be of one color because it reflects the light of that color and absorbs all others. Under a single color or monochromatic light, it might appear to be of another color or almost black, depending upon what colors and how much light it reflected.

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**Section VI****CHARACTERISTICS OF OPTICAL SYSTEMS****31. GENERAL.**

a. Military fire control instruments employing optical systems are required for a great variety of purposes. To cite a few, these instruments are used to see great distances, to magnify small objects, to determine positions, and to gage height and distance.

**32. MILITARY TELESCOPES.**

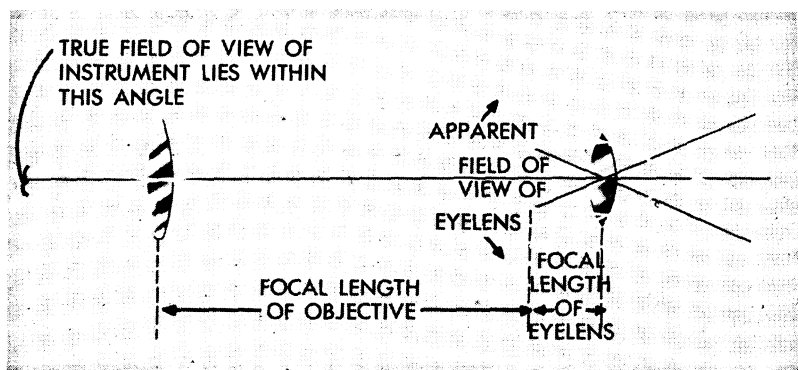
a. Necessary characteristics of military optical instruments are usually the following: a minimum of weight and bulk; the largest possible field of view and brightness of image consistent with the necessary magnifying power and freedom from distortion; and ruggedness and simplicity. The instrument must form an erect image of the object. In the majority of instruments, the optical system must include a reticle pattern.

**33. MAGNIFICATION.**

a. Magnification of a telescope optical system depends both upon the objective and the eyelens or eyepiece. Although the eyepiece magnifies the image formed by the objective, it cannot supply sharpness or detail lacking in the image. The shorter the focus of the eyepiece, the greater is the magnifying power.

**34. FIELD OF VIEW.**

a. The *true field of view* of any optical instrument is the extent—the width and height—of what can be seen at one time by looking through the instrument. The field of view is cone-shaped; it becomes



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**Figure 51 – Field of View Limited by Optical Possibilities of Eyepiece**

wider and higher as the distance is increased from the objective. In the majority of fire control instruments, the angle of the true field of view is relatively small.

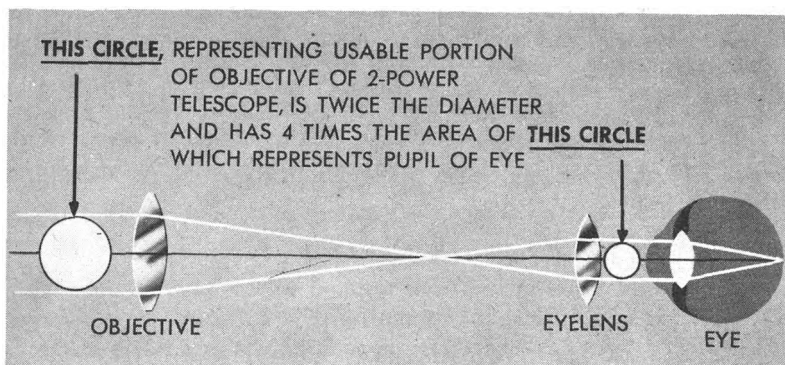
b. Inasmuch as the objective gathers the light from the object and forms the real image that is magnified by the eyepiece, it might be assumed that the size of the objective would govern the size of the field of view. This is rarely the case. Actually, the true field is limited by the optical possibilities of the eyepiece (fig. 51). The maximum area of the field which might be imaged by the eyepiece, if it were not for a number of limiting factors, is termed the *apparent field of view*.

c. An apparent field of view of 45 degrees may be considered as a practical maximum for a highly corrected eyepiece. Thirty-five or 40 degrees is a more common value, and in the more simply constructed eyepieces, the field may be only 25 or 30 degrees. This apparent field of view, divided by the power of the eyepiece, determines the maximum value of the true field for any given magnification. For example, if an eyepiece corrected for an apparent field of 40 degrees is used, and a telescope of 10-power is required, the maximum true field of the instrument would be only 4 degrees.

d. Other factors can further limit this maximum true field. The components of the erecting system of the instrument might not be sufficiently large to transmit the full useful area of the image and would decrease the field. Some aperture in the instrument might be so small as to restrict the field.

### 35. BRIGHTNESS OF IMAGE.

a. The more light of an evenly diffused nature that can be brought from the object to the eye, the brighter and clearer will be



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**Figure 52 — Comparison of Light Entering Eye With 2-Power Telescope**

the image that is formed. This characteristic is known as *brightness of image*. The point where it is brought to the eye is called the *exit pupil* of the instrument.

b. When one looks at a distant object with the naked eye, parallel rays of light from the object enter the pupil of the eye and form an image of a certain size on the retina. When one uses a telescope of 2-power magnification, the light forms an image on the retina which is twice as high and twice as wide, or an image that covers four times the area of the image that would be formed by the naked eye (fig. 52).

c. If there were no loss of light, the magnified image would have the same brightness in each part of its area as in each part of the smaller image seen by the naked eye because the 2-power telescope collects four times as much light to distribute over the larger area of the retina. In practice, however, there is always a considerable loss of light by absorption in the lenses and by reflection at the surfaces of the optical elements. While this loss may be as great as 75 percent, every effort is made to reduce the loss to a minimum.

d. A contributing factor in brightness of image is an objective lens aperture (usable portion) large enough to permit the eyelens to produce an emergent beam that will fill the pupil of the eye. On the other hand, enlarging the objective beyond this point affords no greater brilliance because additional light is prevented by the iris from entering the eye.

e. During the day, the diameter of the pupil of the eye is from  $\frac{1}{10}$  to  $\frac{2}{10}$  inch in diameter. At night, the pupil may dilate until its diameter is from  $\frac{1}{4}$  to  $\frac{3}{10}$  inch. A telescope or other instrument for use at night should have an exit pupil aperture of this size. The aperture of the objective must then be sufficiently large ( $\frac{1}{4}$  to  $\frac{3}{10}$

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inch times the magnification of the instrument) to insure that the pencil of light will fill the pupil of the eye. During the daytime, the useful aperture of the objective of such an instrument is correspondingly smaller.

f. Some of the telescopes used for military fire control purposes are made with objectives smaller than that indicated by this formula. Brightness of image has been sacrificed to obtain a more compact instrument.

### 36. EYE DISTANCE OR EYE RELIEF.

a. The *exit pupil* is the term applied to the rays of light which emerge from any optical instrument with a collective or convergent eyepiece and form the image that is seen by the eye. The exit pupil of such an instrument can be seen as a brightly illuminated disk floating in space if the instrument is directed toward a bright source of light and its eyepiece is held about 15 inches from the eye. The position of the exit pupil can be fixed on a screen of translucent paper or on a plate of ground glass. In this manner, the distance of the exit pupil from the last glass surface of the eyepiece can be measured.

b. The full field of view of a telescope can be seen only when the pupil of the eye of the observer is at the same position as the exit pupil. The distance from the eyelens to the exit pupil is termed the *eye distance* or *eye relief*. The eye must be placed at this distance from a collective eyepiece in order to see most effectively through the instrument.

c. If the eye distance of an instrument is so limited that the exit pupil cannot enter the eye pupil, or if the eyelashes touch the eyelens, observation through the instrument will become tiresome and the instrument cannot be used most effectively. When the instrument is to be mounted on a weapon, if the eye distance is not considerable, recoil of the gun will make observation dangerous.

d. In the designing of the instrument, the proper location of the exit pupil must be given most careful consideration. If it is too far back, the eyepiece will become too bulky; if it is placed too close, the user of the instrument will suffer discomfort and will be unable to use the instrument to the best advantage. Proper eye distance depends on the purpose for which the instrument is to be used.

### 37. INTERPUPILLARY DISTANCE.

a. The spacing between the pupils of the eyes makes stereovision possible because each eye views an object from a slightly different viewpoint. From the fused image gained from the two viewpoints the observer receives the impression of depth. This spacing of the eye pupils varies to a considerable degree in different individuals and is known as *interpupillary distance*. This distance is measured in millimeters by the Interpupillometer M1.

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b. In the designing of instruments to be used by both eyes of an individual, provision must be made to adjust the spacing between the eyepieces of the instrument to conform to the interpupillary distance of different observers. The interpupillary distance of such instruments generally is adjustable from 58 to 72 millimeters because the eye spacing of nearly everyone is within this range. If the interpupillary distance of an individual is greater than 72 millimeters or less than 58 millimeters, he is incapable of using instruments of this type to the best advantage.

### 38. FOCUSING.

a. For perfect focusing of a monocular instrument under all conditions, two adjustments are necessary. If the instrument has a reticle, means must be provided for adjusting the distance between the reticle and the objective so that there will be no parallax (par. 49). Also, the distance between the eyepiece and the reticle must be adjusted for the eye of the observer. In a binocular instrument, it also is necessary to adjust the instrument to conform to the interpupillary distance of the eyes of the observer.

b. If the focal length of the objective is short and the targets in general are at a great distance, the objective may be adjusted for a target at an infinite distance when the instrument is assembled in the factory and no field adjustment is provided. This is the case with most fire control instruments and low-power telescopes.

c. Focusing eyepieces are commonly found on fire control instruments. This adjustment is primarily designed for focusing the instrument for different eyes and is referred to as the *dioptric movement*. The two lenses of the eyepiece are mounted in a single tube and its distance from the reticle or focal point of the objective or erecting system can be adjusted by rack and pinion, by a simple draw tube, or by rotating the entire eyepiece causing it to screw in or out.

d. On fire control instruments, a graduated scale is generally provided around the eyepiece. This scale is calibrated in diopters. The *dioptric* is the unit of measurement of the converging power of lenses and the eyes (par. 119). For a normal eye, the scale on the eyepiece is set at zero. If a positive 2-diopter spectacle lens is commonly worn, the eyepiece should be set at +2, provided the spectacles are removed, as they should be. After carefully focusing the instrument once, the reading of the eyepiece should be memorized and used for future focusing.

e. Low-power telescopes are frequently made without any means for focusing. Such an instrument is termed a *fixed-focus telescope*. When assembled, such an instrument is often so adjusted that light

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emerging from the instrument, instead of being parallel, appears to diverge from a point 40 to 80 inches in front of the eyelens. A telescope so focused is more readily adaptable to the eye of the average observer than one focused so that the rays of light are parallel. A fixed-focus instrument is much simplified and can be made entirely waterproof. However, if the power of the telescope is greater than 3.5 or 4, the accommodation of the average eye is not sufficient to permit its use.

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**Section VII****ABERRATIONS AND OTHER OPTICAL DEFECTS****39. GENERAL.**

a. An *aberration* is a lens or prism imperfection resulting in an image that is not a true reproduction of the object.

b. In designing an instrument, correction is usually made for optical defects with special attention being given to the use to which the instrument is to be put. Correction is achieved by using lenses or prisms made of two or more kinds of glass (called *compound lenses* or *compound prisms*), by eliminating rays which would be refracted through the outer edges of lenses (called *marginal rays*), and by equipping the instrument with a suitable eyepiece.

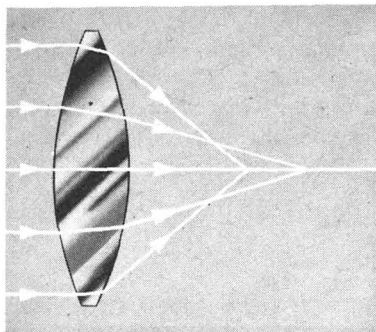
c. There are six general types of aberrations—spherical and chromatic aberration, astigmatism, coma, curvature of field, and distortion. Other factors which may affect the operation of the optical system of an instrument are resolving power, Newton's rings, light loss, and parallax.

**40. SPHERICAL ABERRATION.**

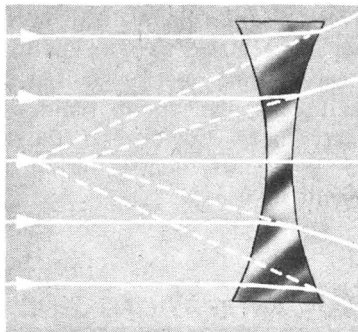
a. Light rays refracted through a spherical lens near its center and those refracted through the outer portion or margin do not intersect the axis at a single point. The outer rays of a convergent lens intersect the axis closer to the lens than the more central ones (fig. 53), and the opposite is true of a divergent lens (fig. 54). The result is a blurred image. This fault is common to all single spherical lenses and is termed *spherical aberration*.

b. The thickness of a lens and its focal length influence the amount of spherical aberration. Spherical aberration is least in thin lenses of long focal length.

c. If the lens were ground with constantly flattening curves to the edge (parabolic), instead of being ground with each refracting surface as a true portion of a sphere, the rays would be caused to cross the axis at a single point and a sharp image would result. Such lenses, however, would be too difficult and costly to manufacture. Instead, two other methods are utilized either singly or together, which satisfactorily eliminate spherical aberration.

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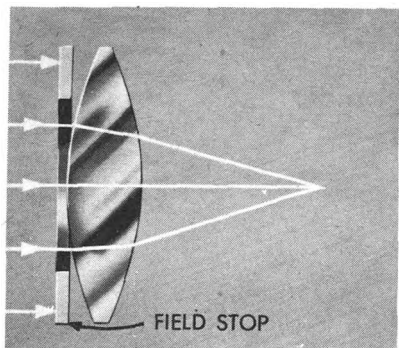
**Figure 53 — Spherical Aberration of Convergent Lens****Figure 54 — Spherical Aberration of Divergent Lens**

d. **Field Stop or Diaphragm.** Spherical aberration can be reduced by using a field stop or diaphragm. The central portion of a lens is most free of spherical aberration. Tests of a lens will show how much of the area around the axis may be safely used to form a sharp image. This area is called the *least circle of aberrations*. The usual practice is to mask out all rays passing through the lens beyond this circle (fig. 55). The mask used for this purpose is called a *field stop*. It is a flat ring or diaphragm of metal or other opaque material covering the outer portion of the lens. It stops the rays from entering the margin of the lens but, as it cuts down the effective size of the lens, it limits the amount of light passing through the lens.

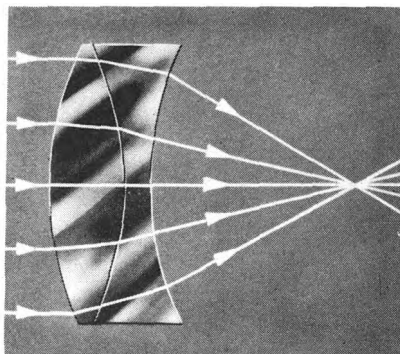
e. **Compound Lens.** In fire control instruments, spherical aberration is commonly eliminated by the use of a convergent and a divergent lens cemented together to form a single element known as a compound lens (par. 64). The compound lens approximately corrects spherical aberration because the concave curves of the divergent lens neutralizes the positive aberration of the convex curves. The refractive power of the combination is retained by the proper choice of indices of refraction for each of the two lenses. A lens in which spherical aberration has been minimized or eliminated is said to be *aplanatic*.

#### 41. CHROMATIC (COLOR) ABERRATION.

a. Upon being refracted through a prism, light rays of different wave lengths are dispersed into bundles of rays of the same wave length, forming a spectrum of various colors (par. 29). The rays of different colors are refracted to different extents, red undergoing the least refraction and violet the most. Inasmuch as a lens is composed of an infinite number of prisms, this dispersion also exists where light is refracted through a lens. This produces an optical defect, present in every uncorrected single lens, known as *chromatic aberration* or

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**Figure 55 — Effect of Field Stop on Spherical Aberration****Figure 56 — Effect of Compound Lens on Spherical Aberration**

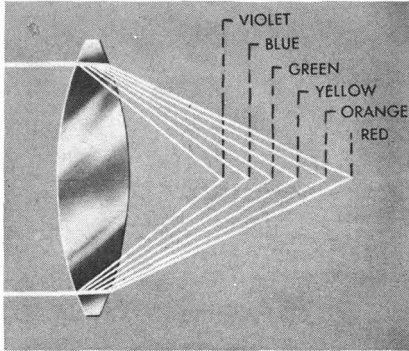
**chromatism.** The violet rays focus nearer the lens than the red rays (fig. 57), and the rays of the other colors focus at intermediate points. Thus, such a lens would have a different focal length for each color, and the image would be fringed with color.

**b. Correction of Chromatic Aberration of Lens.** Like spherical aberration, chromatic aberration is corrected by making a compound lens of two separate lenses, one positive (convergent) and one negative (divergent). The positive lens is made of crown glass while the negative lens is made of flint glass (fig. 58). The high color dispersion of the flint glass negative lens is sufficient to compensate for the lower color dispersion of the crown glass positive lens, without entirely neutralizing its refractive power. A compound lens so designed is said to be *achromatic*. Construction of a lens of this type is described in paragraph 64 b.

**c. Spherical and chromatic aberrations usually are corrected by the same two elements of a compound lens.** In some lenses, the negative element is plano-concave (only one surface ground spherically). In this case, the adjacent surfaces are ground to compensate for these two defects. In others, the inner curves of the lenses are calculated to eliminate chromatic aberration and the outer curves to remove spherical and other types of aberration.

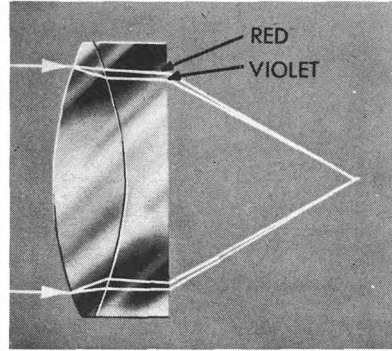
**d. Correction of Chromatic Aberration of Prism.** The majority of prisms employed in fire control equipment are used to reflect light; some are used to *refract* light. When light is reflected by a prism, there is no chromatic aberration because the light rays are not divided up or dispersed. Only when light is refracted by a prism, as through a measuring wedge of a range or height finder, is the light affected by chromatic aberration.



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Figure 57 — Cause of Chromatic Aberration



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Figure 58 — Correction of Chromatic Aberration of Lens

e. Chromatic aberration in a refracting prism is corrected in much the same manner that it is in a lens. Two prisms made of different kinds of glass are cemented together (fig. 59). The prism having the larger refracting angle and which is to be the means of refracting the image from its normal path is made of crown glass. The prism having the smaller refracting angle is made of heavy flint glass which has a large dispersion of colors. The flint prism, by reason of its large dispersion, neutralizes the dispersion caused by the crown prism without entirely neutralizing the deviation of the path of the image. This compound prism is known as an *achromatic prism*.

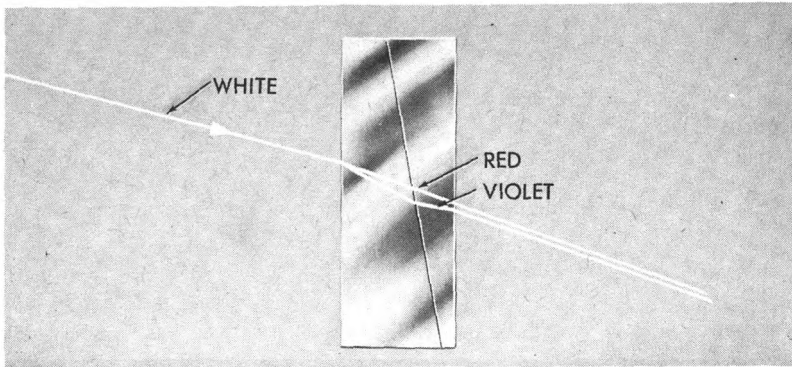
## 42. ASTIGMATISM.

a. **Astigmatism** is a lens aberration which makes it impossible to get images of lines equally sharp when these lines run at angles to one another. This optical defect is found in practically all but relatively complex lenses known as *anastigmats* which are particularly designed to eliminate this condition.

b. A perfect lens refracts all the rays from a point of light to a sharply defined point of light on the image. The rays which form each point of light of the image are refracted as a cone (fig. 60). Each cross section of one of these cones is circular in form, each successive circle becoming smaller until the focal point is reached.

c. In the grinding process, one or both refracting surfaces may become partly cylindrical instead of entirely spherical. The unequal curvature gives the lens two different focal planes. One of these brings lines in one direction into sharp focus; the second sharply focuses lines at right angles to the other lines.

d. A lens with spherical or plane faces properly ground will not show astigmatism for points near the axis, but will show astigmatism for points off the axis. The face of the lens is then presented



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**Figure 59 – Correction of Chromatic Aberration of Prism**

obliquely to the incoming light rays. Cross sections of the cone of light refracted by the lens become successively narrow ovals until they become a line in the vertical focal plane; then they become broader ovals until they are circular; and then they again become a line in the horizontal focal plane, at right angles to the first line (fig. 61). Between the two focal planes is an area known as the *circle of least confusion*. It is in this plane that the most satisfactory image is secured.

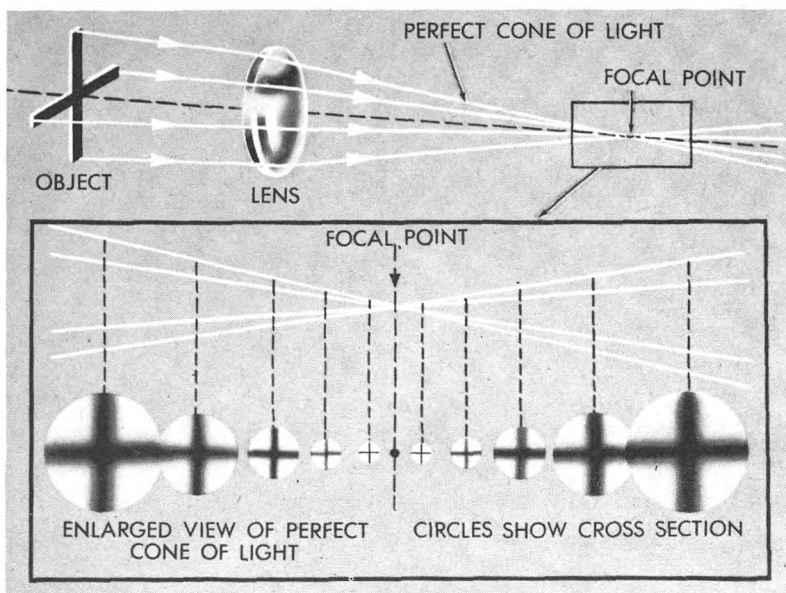
e. **Correction for Astigmatism.** Astigmatism is eliminated in the same manner as spherical and other aberrations. Lenses are made of optical glasses possessing different degrees of refraction, ground to different curvatures, so that the aberrations of all types cancel each other.

#### 43. COMA.

a. Coma is due to unequal refracting power of the various zones or concentric ring surfaces of a lens. It is caused by the rays from the various zones coming to a focus at slightly different points so that they are not exactly superimposed. It appears as blurring of the images at the edges of the field.

b. The image of a point of light is formed by a cone of light rays refracted through a relatively wide portion of a lens. The lens may be considered to be divided into concentric circular zones or rings of varying thickness. To form a sharply defined point of light, the rays from each zone must come to a focus at exactly the same place in the focal plane.

c. In a lens producing coma, rays of light refracted through the inner zone form a well-defined image of the point. Rays refracted through the next zone form a larger, less-defined image of the point

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**Figure 60 — Proper Refraction of Point of Light**

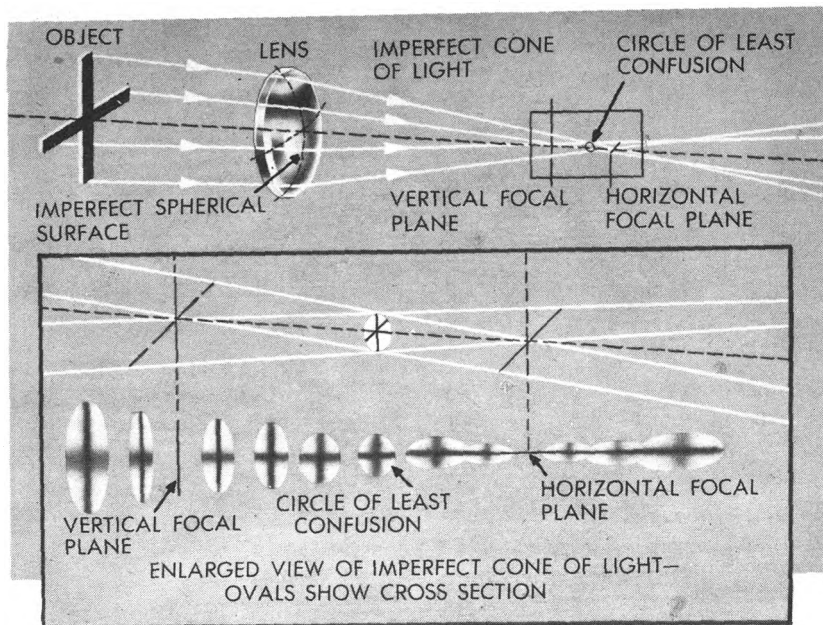
which is offset slightly from the first. The image formed by each successive zone is larger, less defined, and farther removed from the initial point of light (fig. 62). The displacement of the successive images is in a direction toward or away from the center of the field of the lens.

d. The total image of the point may be any of a wide variety of patterns, an egg-, pear-, coma-, or comet-shaped blur (fig. 63). Its general appearance of a comet gives it the name of coma. When viewed under a microscope, a point of light influenced by coma may have a very fantastic shape due to its being affected at one time by all types of aberrations. Inasmuch as coma causes portions of points of light to overlap others, the result is blurred images of objects in the portion of the field affected by coma.

e. **Correction for Coma.** In producing compound lenses, the several types of glass and the curves of the various faces are carefully chosen to give approximate correction for coma as well as for other aberrations.

#### 44. CURVATURE OF FIELD.

a. The field of a lens is the area in which the real image produced by the lens is formed. This area should be flat in order to form an undistorted image. When it is not flat, but is concave or saucer-

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**Figure 61 – Astigmatic Refraction of Point of Light**

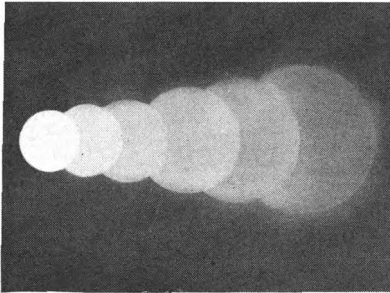
shaped, the condition is termed curvature of the field. An ordinary reading glass plainly shows curvature of the field. In fire control equipment, this defect does not necessarily cause distortion of a serious nature.

b. Curvature of the field is readily visualized by assuming that a cross is imaged by a lens with this defect (fig. 64). Rays from points of light at the ends of the arms of the cross are brought into focus nearer the lens than rays from the center of the cross. If the lens is focused on the center of the cross, the ends of the arms are not in sharp focus, and vice versa. This is particularly disadvantageous in a photographic lens where a flat plate or film is used. If the image is to be in focus over the entire plate, the image also should be flat.

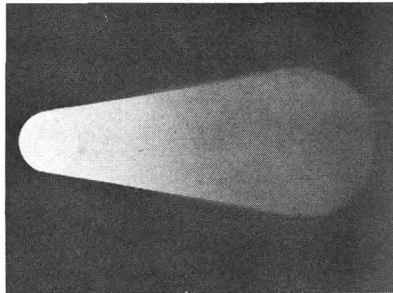
c. **Correction for Curvature of Field.** Flatness of the field is secured by opposing the curvature of one surface or component with a contrary curvature in another. Field stops or diaphragms may also be used to restrict the passage of undesired rays.

**45. DISTORTION.**

a. Distortion is a form of aberration in which the relative location of the images of different points on the object is incorrect. When imaged by a lens having this defect, a straight line extending across

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**Figure 62 — Formation of Coma, Greatly Magnified**

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**Figure 63 — Appearance of Coma, Greatly Magnified**

the field is curved. This is a serious defect in instruments of high magnifying power because the amount of distortion present is increased in proportion to the power of the instrument.

b. Distortion (fig. 65) is caused by rays of light from different points being refracted by dissimilar portions of a lens. When a line extends across the field, rays from the middle of the line strike the lens nearer its center. These rays are refracted at a different angle from that of rays striking near the margin of the lens, giving a curved instead of a straight appearance to the image.

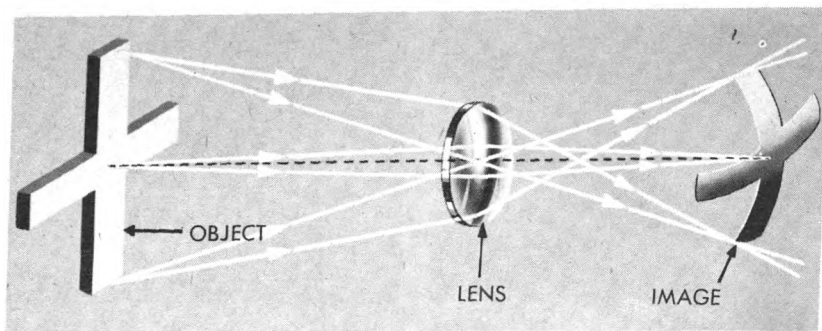
c. If the curvature of the lines of the image is away from the center of the lens, the distortion is termed *barrel-shaped* (A and B, fig. 65). If the lines curve toward the center, the distortion is called *hourglass* or *pincushion* (C and D, fig. 65).

d. While distortion in a convergent lens usually produces the hourglass effect (fig. 66), and in a divergent lens the barrel-shaped effect, distortion of either type may result from an improperly placed field stop: A field stop behind a lens may cause marginal rays to be refracted more outwardly, slightly expanding the image, while the reverse may be true if the field stop is in front of the lens.

e. **Correction for Distortion.** Distortion is removed by grinding the lens to a shape which will permit the stop to be placed in front of or behind the lens, or by placing the field stop between a pair of lenses. In the latter case, one form of distortion neutralizes the other and the lens is said to be *rectilinear*, indicating that lines are rectified. A lens that is free from distortion is called an *orthoscopic* lens.

#### 46. RESOLVING POWER.

a. When two points viewed through a lens are so close together that they can not be distinguished as two distinct points, these points are not *resolved*. To make separation of such points possible a lens of greater *resolving power* is required.

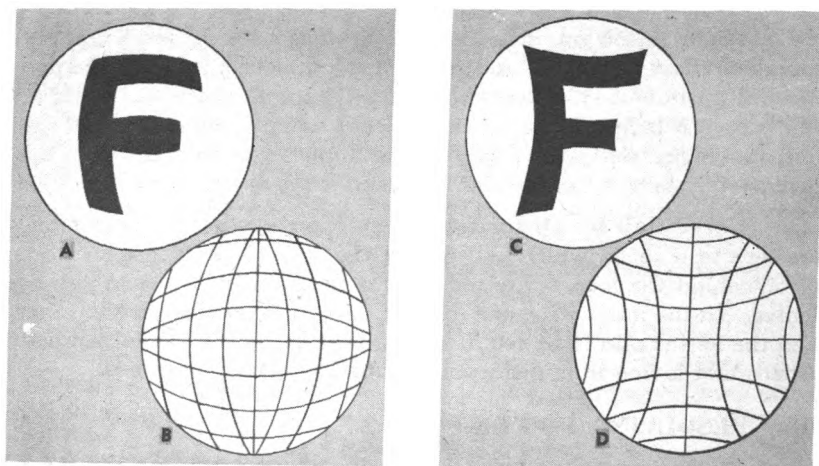
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**Figure 64 – Curvature of Field**

b. It might be supposed that a point of light on the object on being refracted through a high quality compound lens would form a single point of light on the image. However, a number of factors tend to enlarge the point of light so that it merges with another point close to it.

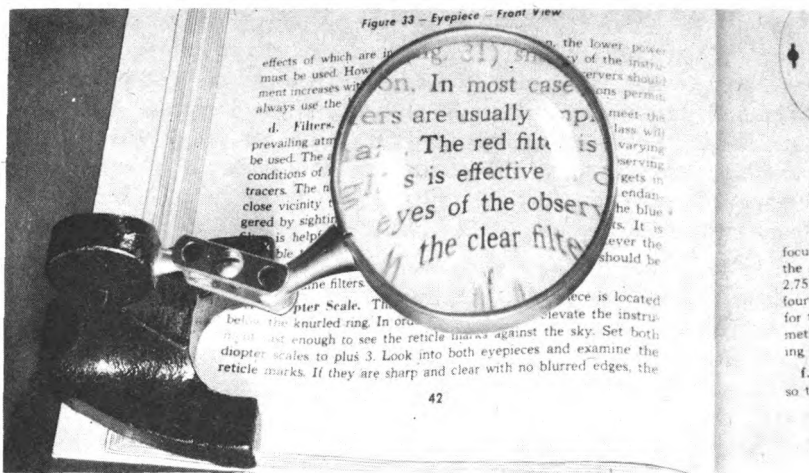
(1) Diffraction causes the image of a point of light to become a tiny disk of light surrounded by a series of concentric rings of light which rapidly fall off in intensity, a minute bull's-eye target of light. This can be demonstrated to the best advantage by sharply focusing the lens on a true star in order to get the image of a single point of



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**Figure 65 – Barrel-shaped (A and B) and Hourglass (C and D) Distortion**

Properties of Light



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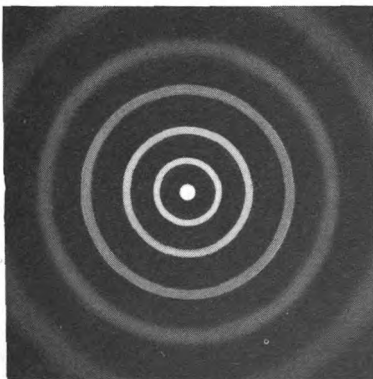
Figure 66 — Hourglass Distortion in Magnification by Reading Glass

light (fig. 67). The images of more detailed objects are made up of myriads of these tiny bull's-eyes.

(2) Aberrations increase the size of the central disks of the diffusion patterns. As these are corrected, the disks become smaller.

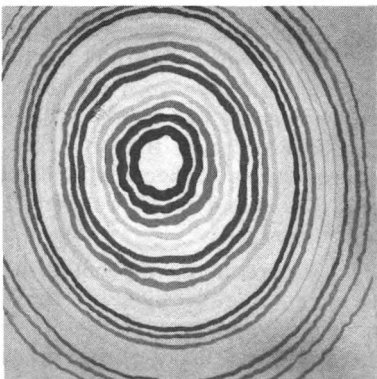
(3) Diffusion, or scattering of light, sets the final limit to the sharpness of the image formed by a lens.

c. In practice, the resolving power of a lens selected for a specific purpose is usually so great that any lack of sharpness of detail is too slight to be observed and, therefore, too slight to be objectionable in the performance of the service for which the lens is intended.



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Figure 67 — Diffraction Pattern, Greatly Magnified



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Figure 68 — Newton's Rings, Greatly Magnified

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**47. NEWTON'S RINGS.**

a. When positive and negative lenses of slightly unequal curvature are pressed one against the other, irregular bands or patches of light and darkness or color appear between the surfaces. This pattern is called *Newton's Rings* (fig. 68), after Sir Isaac Newton who directed attention to it. This condition is a defect if it occurs in a compound lens. It may be utilized to advantage as a means for testing the accuracy of grinding and polishing lenses.

b. When testing lenses for accuracy of grinding and polishing, a test lens having the desired curvature is used. The test lens is placed in contact with the lens to be tested, care being taken that both surfaces are perfectly clean and dry. When the lenses have been squeezed together, if the lens being tested is perfect, the air film between the two lenses will be of uniform thickness and the color will be uniform all over the surface. Irregular bands or patches of color show that the surface of the tested lens is not perfect and point out clearly the parts of the lens needing attention. If the lenses are viewed by daylight, the rings will be colored; if viewed by pure white light, the rings will be alternately black and white.

**48. LIGHT LOSS.**

a. Whenever light rays strike the surface of any lens or prism, a certain amount of light is lost by reflection. Light is absorbed by every element it strikes or travels through. The more elements in the optical system, the more light is lost by absorption.

b. Light loss has been greatly reduced by coating the surfaces of elements which are intended only to refract light (chap. 4, sec. II). The additional light transmitted by instruments in which various elements have been coated produces brighter, more effective images.

**49. PARALLAX.**

a. *Parallax* is apparent motion of the reticle with respect to the field of view of an optical instrument. It is due to incorrect adjustment of objective position, so that the focal points of distant objects and the reticle are different. When the cross line or reticle is not in the focal plane of the objective, the image and the reticle are not magnified simultaneously and both are not in focus at the same time. This displacement will render all measurements made with the reticle inaccurate.

b. Correction for parallax in some instruments can be made by focusing the objective. If the instrument is provided only with a focusing eyepiece, as is the case of most fire control instruments, the objective is adjusted during manufacture or maintenance to eliminate parallax for an object at a specified distance from the instrument. This distance is chosen so that parallax will be negligible for all average operating distances.



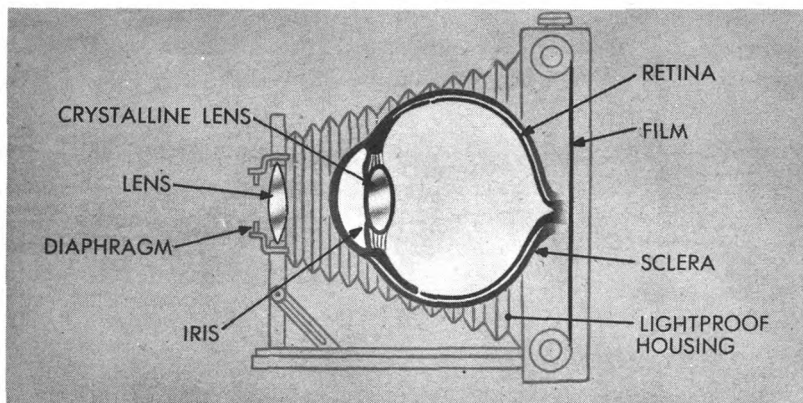
## CHAPTER 3 — THE HUMAN EYE

### Section I

### GENERAL

#### 50. COMPARISON OF EYE AND CAMERA.

a. A high-grade camera closely resembles the eye in basic essentials. Each has a compound lens to refract light rays and to project them to a definite point by means of focusing. Each has a means of shutting out all light, a diaphragm to regulate the entering light, a sensitized surface to receive and record optical images, and a light-proof chamber to protect the receiving and recording mediums (fig. 69).



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*Figure 69 — Comparison of Eye and Camera*

### Section II

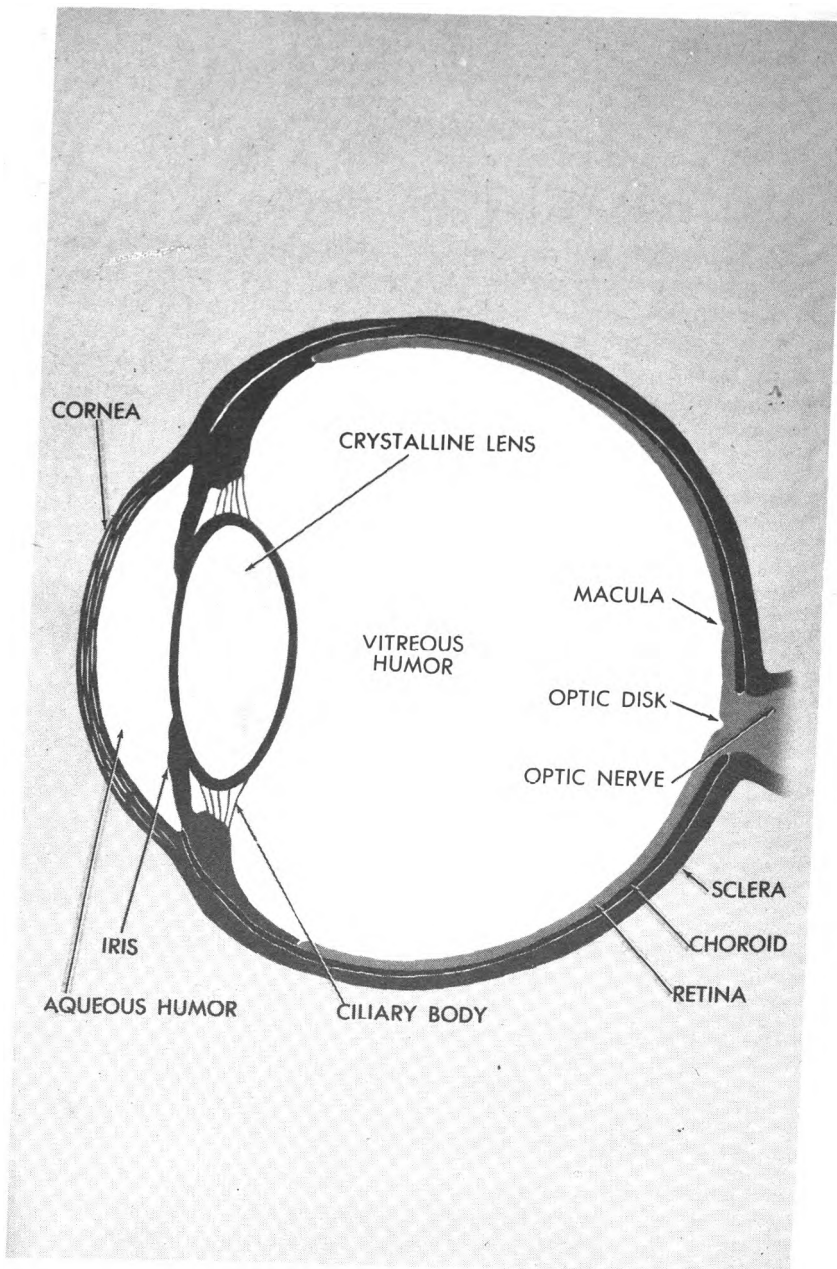
### CONSTRUCTION

#### 51. STRUCTURE OF THE EYE.

a. The eye is a bulbous organ which rotates through quite a wide range in a socket in the bone structure of the head. Muscles control the eyes in associated movements to a considerable extent and in individual movement to a lesser degree. Protection and shade are furnished by the eyelids, lashes, and brows.

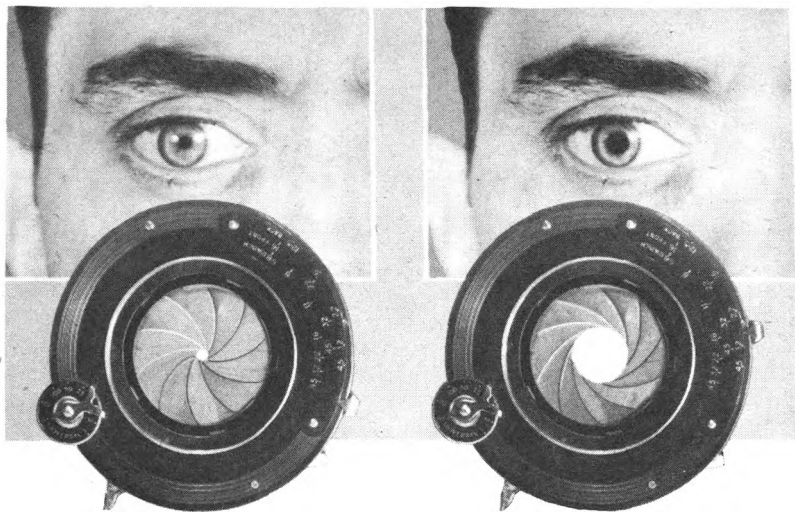
b. The eye has three coats which afford it protection, supply it with nutrition, and transmit visual impressions to the brain (fig. 70).

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**Figure 70 — Phantom View of Structure of Eyeball**



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**Figure 71 – Action of Iris Compared With Camera Diaphragm**

It has a refracting mechanism consisting of the crystalline lens, cornea, aqueous humor, and vitreous humor; together, these form a compound lens. The shape of the lens is changed by the ciliary body to change the focus of the lens. The iris serves as a diaphragm to regulate the amount of incoming light.

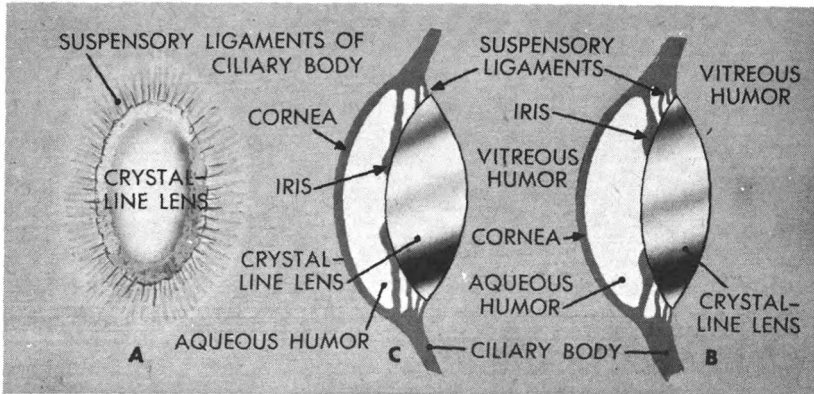
c. The response mechanism of the eye is centered in a small area called the *macula* on the inner coat or *retina* and in a still smaller spot in the center of the macula called the *fovea*. Sensations of light are received by tiny cones and rods attached to nerves and distributed over the fovea, macula, and retina. These sensations are transmitted to the brain by the optic nerve at the lower rear of the eyeball.

## **52. THREE COATS OR TUNICS.**

a. The outer of the three coats or tunics of the eye is the *sclera* (fig. 70). It is tough, white, and flexible and is the white portion of the eye normally seen. The slightly protruding transparent portion at the center front of the eye, the *cornea*, is part of this coat. The cornea and the transparent liquid or *aqueous humor* behind it are parts of the refracting mechanism of the eye.

b. The middle coat, the *choroid*, is a deep purple layer made up of veins and blood vessels which supplies nourishment to the eye tissues. The coloring of the choroid forms a dark housing and prevents internal reflection of light rays within the eye.

c. The inmost coat of the eye is the *retina*, a highly sensitive layer of nerve fibres by means of which visual impressions are trans-



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**Figure 72 – Suspension and Action of Crystalline Lens**

mitted to the brain. The retina is a part of the response mechanism. The interior of the eye is filled with a jelly-like substance, the *vitreous humor*, which is transparent.

### 53. REFRACTING MECHANISM.

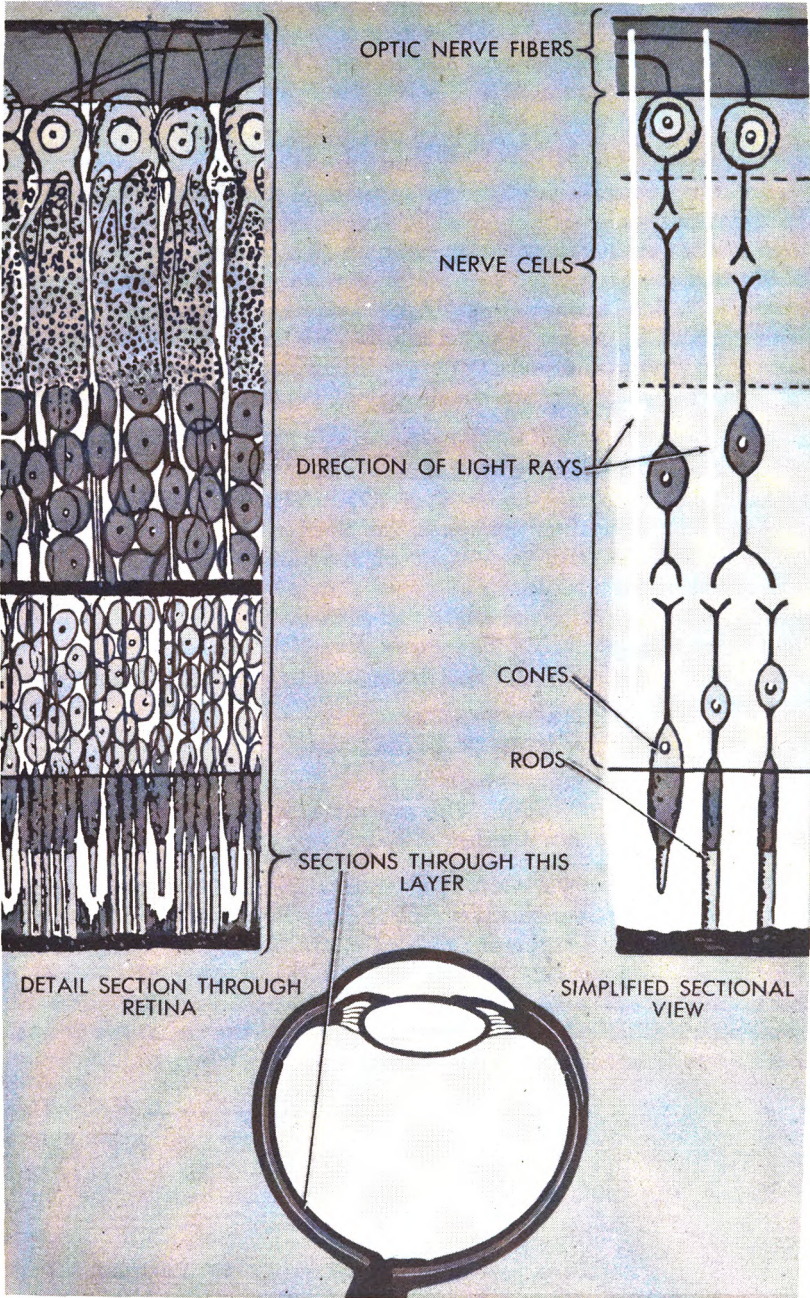
a. The chief refracting surfaces of the eye are those of the cornea and the crystalline lens. The cornea provides the greater portion of the refraction. The crystalline lens supplies a variable degree of refraction which permits the eye to focus on near or distant objects. This gives to the eyes the ability to see far or near objects distinctly and is termed the power of accommodation.

b. The iris is a diaphragm which contracts and dilates to regulate the amount of light entering the eye (fig. 71). The iris is the colored portion of the eye around the pupil. The pupil is the circular opening in the center of the iris. Its size is limited by the contraction or dilation of the iris. It appears black because of the darkness of the inside of the eyeball.

c. The crystalline lens is transparent, and is suspended by the ciliary body which encircles it (A, fig. 72). The front of the lens rests against the aqueous humor, the rear against the vitreous humor. The suspensory ligaments of the ciliary body draw upon or release the outer edges of the lens to change its refracting power by altering its shape.

d. The lens is double-convex and when the eye is relaxed, the front surface is flatter than the rear (B, fig. 72). With the lens in this condition, the eye will focus upon distant objects. To increase the refractive power of the lens for focusing the eye upon a close object, the surfaces are made more convex by the suspensory liga-





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Figure 73 — Cones and Rods of Retina

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ments of the ciliary body. The front surface of the lens, being in contact with the liquid aqueous humor, changes its curvature to a greater extent than the rear surface which contacts the more solid vitreous humor (C, fig. 72).

#### 54. RESPONSE MECHANISM.

a. The response mechanism consists of the *retina* (fig. 73) or thin, inner coat of the eyeball which is sensitive to light, a small area of the retina called the *macula* which is more sensitive to light, and a tiny yellow spot in the center of the macula termed the *fovea centralis* which is even more light sensitive. The cause of light sensitiveness of these areas is an infinite number of visual cells known as *cones* and *rods*. They are connected by nerves to the optic nerve which carries the visual messages they receive to the brain.

b. The light sensitive elements or visual cells are of two distinct types called rods and cones (fig. 73). The rods are cylindrical-shaped and longer than the cones; the shorter cones are bulb-shaped. All are so small that they must be magnified to 300 times their actual size to be visible. The cones provide daylight vision, vision where light intensities are high; the rods give twilight vision where light intensities are low. The cones give clear, sharp vision for the seeing of small details and the distinguishing of colors; the rods detect motion.

c. The fovea is a small area of the retina containing cones alone. This area of the retina, therefore, gives the sharpest detail and the best appreciation of color. The macula also is made up largely of cones but it contains a number of rods.

d. The rods are stimulated by a substance known as visual purple to increase their sensitiveness to subdued illumination. This substance builds up and accumulates during the time an eye is becoming accustomed to darkness. An eye affected in this manner is termed a *dark-adapted* eye. The visual purple is bleached out by light. A somewhat similar substance serves the cones in the same way to produce what is known as a *light-adapted* eye.

e. One small portion of the retina is insensitive to all light. This is an area known as the optic disk. It is where the optic nerve enters the eye and is located slightly to one side of the macula. In most instances, this blind spot has no effect on vision because the mind has learned to ignore it.

f. The optic nerve carries visual sensations to the brain. This nerve is really a cable of nerves through which the rods and cones activated by light images send messages to the brain which result in what is termed sight.

## Section III

**BINOCULAR (TWO-EYED) VISION AND STEREOVISION****55. GENERAL.**

a. *Binocular vision* is coordinated two-eyed vision. The two eyes of a person are normally identical and they work together as a team. The muscles used in adaptation and accommodation of the eyes are sympathetic in action; that is, they tend to dilate, contract, and focus together. Both eyes usually meet with the same light conditions and are turned to converge on the same object or field of view. The two images received by the eyes are not seen separately but are fused by the brain into a single image.

b. *Stereoscopic vision*, or *stereovision*, as it is called, is inseparably associated with binocular vision because it is the result of seeing with both eyes. Stereovision is the power of depth perception, the ability to see in depth, or in three dimensions. This power is due to the spacing between the pupils of the eyes, or the interpupillary distance of the eyes, which enables the eyes to see objects from slightly different angles.

c. The ability to record with each eye a slightly different picture or image of the same object often enables the observer to see more of one side of a given object with one eye than with the other. Together, the two eyes see farther around the object than one eye can see. They get a better impression of the shape of the object, its depth, and its position with relation to other objects. This ability is increased through the use of certain fire control instruments.

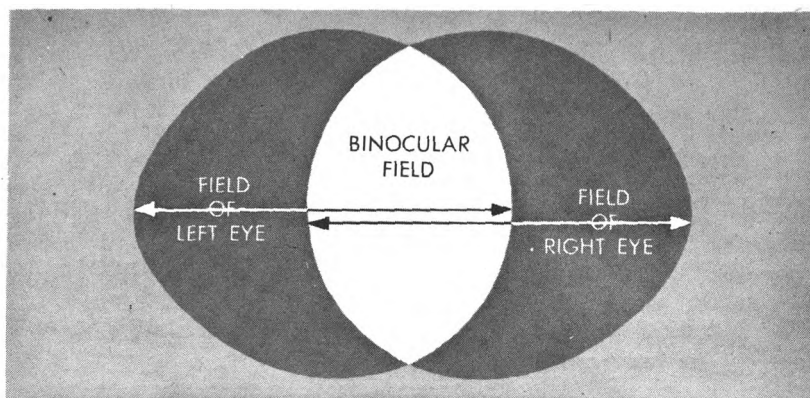
**56. FIELD OF VIEW.**

a. What may be seen by the eyes without movement of the head is termed the *field of view*; what may be seen without movement of the eyes is termed the *field of fixation*. The field of view of the eyes is a horizontal extent of about 160 degrees and a vertical extent of about 70 degrees. When rotated in their sockets, the eyes have an even greater field of vision, both horizontally and vertically. In comparison, the average telescope has a field of view of about 10 degrees.

b. The field of distant vision of immobile eyes is extremely limited. Portions of the field focused on the remainder of the retina are seen indistinctly and serve as a finder to locate objects of interest. When an object of interest is located, the eye turns in its socket until the image falls upon the central portion, the fovea and macula, and distinct vision is secured.

c. The field of vision of both eyes includes portions which are viewed by the right eye, the left eye, and both eyes (fig. 74). The "binocular" field exists only in that portion of the field of view

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**Figure 74 — Field of View of the Eyes**

where the fields of the separate eyes overlap. This explains why stereovision or depth perception is appreciated only in the center of the field of view; it is not apparent, except by association, in the outward portions of the field. The extreme outer areas of the field of view are limited to perception of motion, light, and shadow, and form in two dimensions.

### 57. PRINCIPLES OF STEREOVISION.

a. In a military sense, stereovision implies the ability to recognize the existence of differences in range to objects by visual means only. It is an ability that can be developed by training and practice. Certain fire control instruments are designed to greatly increase the normal stereovision possessed by the individual.

b. There are various means requiring the use of but one eye which can be used to determine which of two objects is the more distant.

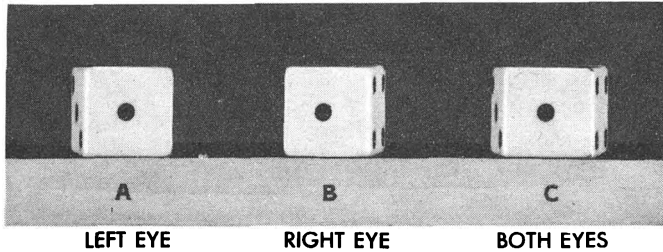
(1) When one object is known to be larger than another and both appear to be the same size, the larger object is known to be more distant.

(2) If an object partly conceals another, the second is recognized as being the farther away.

(3) Differences in the amount of atmosphere (haze), shade, and shadow; the difference in focus (accommodation of the eye) required for more than one object in the field of view; and the relative apparent movement of distant objects as compared with that of near ones when the head is moved from left to right, all influence the estimate of distance.

c. None of these means of depth perception is of value if its contributing factors are lacking. This is difficult to appreciate because



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RA PD 54428

**Figure 75 — Cube as Seen by Left Eye, Right Eye, and Both Eyes**

one or more of these factors are present in almost all commonplace observation and are subconsciously used by persons with two-eyed vision whenever possible to augment their stereovision. Binocular vision without these factors can be obtained by placing two very small objects on a large table and then scanning them with the eyes placed at the edge of the table. To gage their relative distances, the use of both eyes and the employment of stereovision will be required.

d. A simple demonstration of stereoscopic vision is to be had by looking at a near object, such as a small cube. The observer will see a slightly different view with each eye. The left eye will see the front and left side of the cube (A, fig. 75). The right eye will see the front and right side (B, fig. 75). The brain fuses these two separate pictures into a single image giving the impression of depth. The observer sees the front, both sides, and the height of the cube, and in this way, pictures the cube in three dimensions (C, fig. 75).

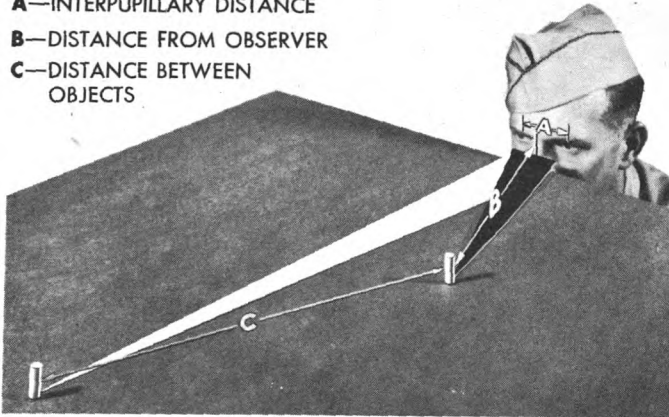
e. In much the same manner, when two objects are observed simultaneously, stereovision enables the observer to judge the relative distance of one object from the other. This can be done with considerable accuracy without utilizing the characteristics which suggest nearness or distance.

f. The ability to distinguish the relative positions of two objects stereoscopically depends upon the interpupillary distance of the observer's eyes, the distance of the objects from the observer, and their distance from each other (fig. 76). Other factors of depth perception being equal, the wider the spacing between the pupils of the eyes, the better appreciation of depth one should be able to secure by stereovision. The farther one object is from the observer, the farther away the second object must be from the first, if the observer is to distinguish their relative positions stereoscopically.

g. When a person looks at two objects and attempts to determine which is farther away, the lines of sight from both his eyes converge or come together to form angles on both of these objects. The

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- A—INTERPUPILLARY DISTANCE  
 B—DISTANCE FROM OBSERVER  
 C—DISTANCE BETWEEN  
 OBJECTS



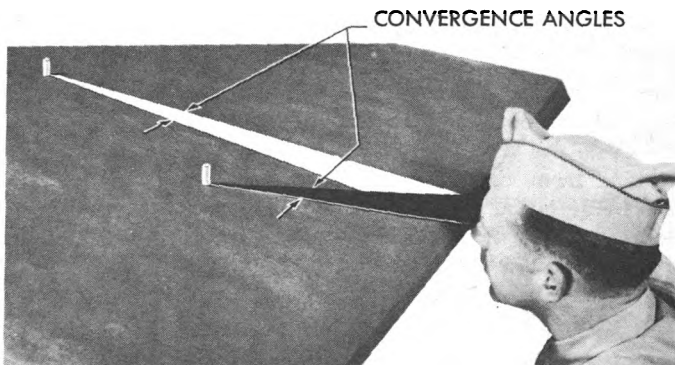
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**Figure 76 — Three Factors Limit Judging of Distance**

angles formed by the converging lines of sight are the *angles of convergence* (fig. 77). If the angles of convergence to both objects appear to be identical, there is no impression of one being farther away than the other. If there is a difference in the angles of convergence to the two objects, one of the objects will appear more distant.

h. The difference between angles of convergence may be slight but the brain possesses the faculty of distinguishing between them. The ability to see stereoscopically is dependent upon the ability to discern the difference between angles of convergence (fig. 78). Keeness of stereoscopic vision is termed *stereo-acuity* or *stereopsis*.

i. Angles of convergence become smaller and the difference between them becomes more difficult to discern as the objects are farther removed from an observer or as their distance from one



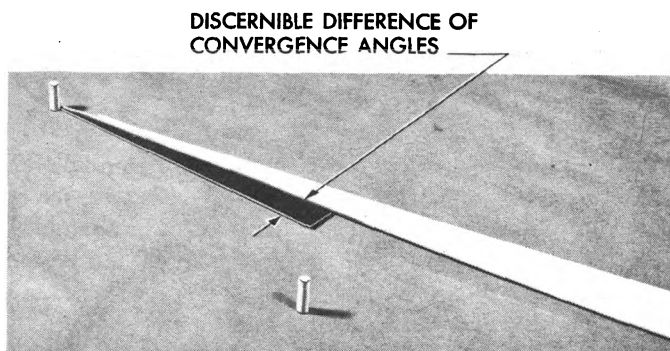
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**Figure 77 — Lines of Sight Form Convergence Angles**

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RA PD 54431

**Figure 78 — Graphic View of Difference Between Convergence Angles Shown in Figures 76 and 77**

another is decreased. This difference is known as the *discernible difference of convergence angles*, and is measured in fractions of minutes and seconds of arc. This provides a means of gaging the ability of observers to see stereoscopically. Keeness of stereovision is measured on a percentage basis, termed *percent steropsis*.

## 58. VISUAL ACUITY AND STEREO-ACUITY.

a. *Visual acuity* is keenness of sight. It is the ability to see near and distant objects clearly in order to compare minute details and to discriminate between them. *Stereo-acuity* is sharpness of sight in three dimensions. It is the ability to gage distance by perception of the smallest discernible differences of convergence angles. Both abilities may be developed by practice and training which aids recognition.

b. **Measurement of Visual Acuity.** The standard measure of the acuteness or keenness of vision is the power to distinguish letters and characters of a specified size at a given distance. These letters, which are called *standard letters*, subtend 5 minutes of arc in each direction. This means that the size of letters to be viewed at 20 feet would be equal in height and width to the distance between two lines at 20 feet if the lines were separated by an angle of 5 minutes of arc. According to this specification, standard letters for viewing at 20 feet are 8.86 millimeters (about 0.35 inch) square, and those for viewing at 120 feet would be 53.2 millimeters (just over 2 inches) square.

c. The customary test for visual acuity is made by placing a test chart 20 feet from the observer. The test chart consists of rows of standard letters. The letters in the various rows are of such size that they would subtend an angle of 5 minutes of arc at distances of

### The Human Eye

10, 15, 20, 25, 30, 50, 80, 100, and 200 feet, respectively. The smallest size of letter the observer is able to read is considered to be the index of his visual acuity.

d. The index of visual acuity is expressed as a fraction, the numerator or first figure being the distance of observation and the denominator or second figure being the standard distance for reading the smallest letters the observer is able to read. For example, if the smallest letters the observer is able to read at 20 feet are those which should be distinguishable at 50 feet, the observer's vision is recorded as being 20/50. Normal vision is 20/20.

e. **Measurement of Stereo-acuity.** The standard measure of stereo-acuity is the ability to distinguish the difference between known divergence angles. The smallest difference between divergence angles that an observer is able to distinguish is known as his *minimum discernible difference of convergence angles* and his stereo-acuity is rated on a percentage basis as his *percent stereopsis*.

f. The minimum difference that can be discerned between two angles of convergence depends upon the vision of the individual observer, his state of training, and other general conditions such as visibility. A well-trained observer should consistently discern an average difference of 12 seconds of arc, and at times, under excellent observing conditions, this difference may be reduced as low as 4 seconds of arc for a series of observations. The average untrained observer should be able to distinguish a minimum difference of 30 seconds of arc between two angles of convergence under normal conditions of visibility.

## Section IV

### DEFECTS OF VISION

#### 59. GENERAL.

a. Common eye defects fall into two classifications: those pertaining to sight itself and those which are the result of muscular disorder. Names ending in "*ic*" signify the condition while "*ia*" signifies the name of the disorder. Likewise, the "*tropias*," derived from the Greek "*op*" meaning sight, signify optical or sight abnormalities, while the "*phorias*," from the Greek "*phora*" meaning movement, signify muscular disorders. The normal eye is said to be *emmetropic*; the person enjoys *emmetropia*. The abnormal eye is *ametropic*; the person suffers from *ametropia*.

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*The Human Eye*

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b. The common eye defects are listed below. Explanations may be found in the glossary.

- Nearsightedness (myopia)
- Farsightedness (hypermetropia or hyperopia)
- Old-sightedness (presbyopia)
- Astigmatism
- Color blindness (dichromatism)
- Night blindness
- Muscular imbalance (heterophoria)
- Double vision (diplopia)
- Squint, cross-eye, walleye (strabismus)

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### Section V

## OPTICAL INSTRUMENTS AND THE EYES

### 60. GENERAL.

a. Optical fire control instruments may be placed in two general classifications: monocular, for the use of one eye; binocular, for the use of both eyes. Both types require certain adjustments to accommodate them to the eye as the use of any optical instruments affects the functioning of the eye itself.

### 61. ACCOMMODATION OF OPTICAL INSTRUMENTS TO EYES.

a. In order that the eye may function properly in the use of a *monocular* instrument, the instrument must be focused to permit light entering the instrument from an object to form a distinct image on the retina without undue effort on the part of the eye-controlling muscles of the observer. The exit pupil (rear opening of the eyepiece) must be sufficiently large to let the maximum of light enter the pupil of the eye. Stray light must be kept out of the eye. In addition, the use of a *binocular* instrument demands that the two optical systems of the unit be properly aligned with each other and conform to the interpupillary distance of the individual.

b. **Focusing.** Precise focusing of the instrument permits light from the object to form a distinct image on the retina. Focusing changes the position of the eyepiece with relation to the focal plane of the objective and the angles at which the light rays are brought to a focus. The eyepieces of focusing-type telescopes generally are

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*The Human Eye*

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calibrated to accommodate for the refracting qualities of the eyes of individual observers. If the instrument is used consistently by an individual, the eyepiece setting can be memorized to expedite the focusing of the instrument. Low-power telescopes have a wider range of accommodation than high-power telescopes. Telescopes in which the magnifying power is 4X or less have a sufficiently wide range of accommodation that a single focus setting will be satisfactory for any observer whose eye correction is not extremely large. They are generally constructed with a fixed-focus eyepiece which cannot be adjusted during operation. They are called *fixed-focus telescopes*.

c. **Use of Spectacles.** If the proper spectacles are worn, the corrected eyes will focus at the normal setting of the instrument. However, the use of spectacles prevents the eyes from coming up properly to the eyeshield of the instrument, permitting stray light to enter the eyes. In addition, the eye may be placed so far from the eyepiece as to restrict the field of view. When the eyes are seriously affected by astigmatism, the observer should not remove his spectacles as no compensating adjustment can be secured by focusing the eyepiece of the instrument.

d. **Eyeshields.** The use and proper fit of the eyeshields should be such that it excludes stray light from the eyes. This is particularly important in night observation, and under conditions of poor illumination, so the pupil may dilate as much as possible. If a monocular instrument is used, the eye not in use also should be shielded from light; if it receives too much light, the pupil of the eye in use will contract sympathetically. Rubber shields at the eyepiece make the most effective seal. Any light used to illuminate the reticle must be held to a bare minimum.

e. **Interpupillary Adjustment.** A binocular instrument must be adjusted to the eye spacing or interpupillary distance of the observer. If this is not done, the lines of sight of both eyes cannot traverse the most effective optical paths of the instrument, the observer will not have full binocular vision, nor view the most distinct images, nor be able to seal out unwanted light from the eyepieces. Practically all instruments of this type are equipped with means for interpupillary adjustment. They are marked with calibrations for such adjustment. The observer should determine his interpupillary distance (par. 37), memorize it, and adjust any such instrument he may use to conform to the spacing between the pupils of his own eyes.

**62. EYE TENSION OR FATIGUE.**

a. Blinking of the eyes is an automatic process resulting from eye tension or fatigue. It will occur in the use of optical instruments because the eyes cannot focus steadily very long without relaxing. It is muscular rather than retinal and is least apparent when the eye is relaxed as when accommodated for distant objects. For this reason, in focusing an instrument, it should be focused for distance and the first distinct focus setting should be used.

b. Fatigue of the eye muscles will be experienced after comparatively short periods of continuous observation. This fatigue is usually greater with low illumination. Inasmuch as the eyes quickly recuperate, frequent rest periods are advisable.

c. A particular type of fatigue results from the use of binocular instruments if not set at proper interpupillary distance. This is due to the fact that both eyes involuntarily adjust themselves so that a single image is formed when the image is focused on the macula of each eye where best vision is obtained. Under ordinary conditions this is done when viewing a distant object. In using an instrument, objects may be at different points and the eyes are placed in a condition of forced equilibrium by the expenditure of an amount of nervous force, resulting in rapid fatigue.

## CHAPTER 4 — OPTICAL COMPONENTS, COATED OPTICS, AND CONSTRUCTION FEATURES

### Section I

## OPTICAL COMPONENTS

### 63. OPTICAL GLASS.

a. **Types.** Two of the most important types of optical glass are known as *crown glass* and *flint glass*. Crown is an alkali-lime glass. Boro-silicate crown glass contains a salt composed of boric and silicic acid. Flint glass contains lead. The refractive indices of these types of glass are listed in paragraph 14 c.

b. **Characteristics.** The characteristics affecting the values of all types of optical glass may be divided into the purely optical properties, which directly influence the light in passing through the glass, and the general qualities of the glass itself. The purely optical properties are constant density (*homogeneity*), transparency, refraction, dispersion, and freedom from color. The general features of optical glass are chemical stability, mechanical hardness, and freedom from internal strain and defects.

(1) Constant density or homogeneity is the most important property. The uniformity of the index of refraction of the glass is dependent upon its constant density.

(2) The greater the transparency, the less light is absorbed and the more light will pass through.

(3) The refractive and dispersive qualities are dependent upon the type of glass. Crown glass has nearly twice the dispersive power (ability to spread the colors of so-called white light) of flint glass.

(4) Freedom of color, while preferable, is not as essential as the other requirements. It is obtained by careful selection of raw materials which must be of the greatest possible purity.

(5) Chemical stability and hardness determine the resistance of the finished optical element to handling and contact with atmospheric moisture.

(6) Freedom from strain depends upon annealing or cooling of the glass in manufacture. Any large amount of internal strain may cause the glass to break during grinding or if subjected to shock at any time after grinding.

(7) Types of defects are known as stones, bubbles, seeds, and striae (layers). Stones are due to solid material that accidentally may get into the molten glass at the time of manufacture. Bubbles are air pockets in the glass. Seeds are very minute bubbles. Striae are wavy bands which appear to be of different density and color than the surrounding medium.



c. **Manufacture.** Although an understanding of the manufacture of optical glass is not essential to a knowledge of elementary optics, some appreciation of the many processes involved will show why fine optical glass is considered a critical material. The finely divided materials are very thoroughly mixed, usually by hand. This mixture is melted in small charges, small quantities being fed to the melting pot at intervals regulated by the melting time of the charge previously introduced. Each charge is brought to a liquid state before the next charge is placed in the pot. The next operation, the fining process, consists of holding the molten glass mixture at a high temperature (sometimes as long as 30 hours) to drive off the bubbles contained in the liquid. To secure homogeneity and prevent striae, the molten glass is then stirred during the gradual cooling of the mass until it is so stiff that the stirrer cannot be moved. The mass is stirred from 4 to 20 hours, depending on the glass and the size of the pot. As soon as the stirring ceases, the pot is withdrawn from the furnace and allowed to cool to about the annealing temperature. It is then placed in an annealing kiln at a temperature of from 400 to 500 degrees centigrade, and slowly cooled to ordinary temperature. Annealing takes from 1 to 2 weeks, according to the size of the batch. When cooled, the pot is withdrawn from the annealing kiln and broken away from the glass.

#### 64. LENSES.

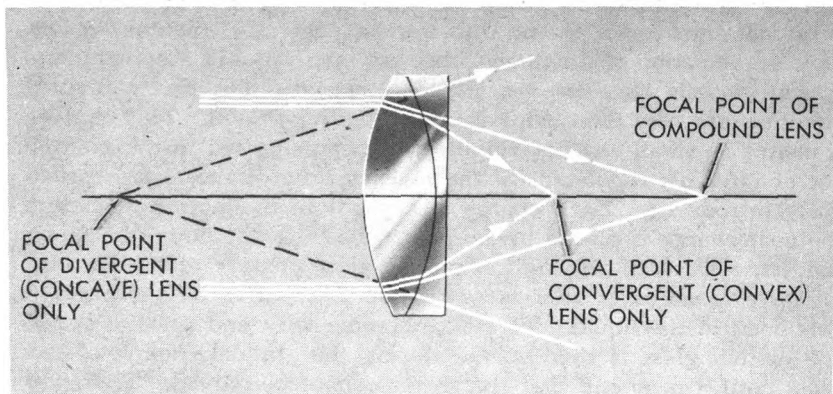
a. **Single Lenses.** Lenses are divided into two general classes (fig. 179). One class forms real images, and lenses in this class are termed *convex*, *convergent*, *positive*, or *collective* lenses. The other class can form only virtual images, and lenses in this class are termed *concave*, *divergent*, *negative*, or *dispersive* lenses.

(1) **CONVEX LENSES.** All convex lenses are thicker in the center than at the edges and will converge light from distant sources and objects. Both faces of a convex lens may be convex, one surface may be convex while the other is flat (termed *plano-* or *plane*), or one face may be convex while the other is concave.

(a) A double-convex lens (fig. 179) is one in which the convex curvature of one face is more powerful than that of the other face. Both surfaces contribute to the converging power of the lens. The greater the convexity of the surfaces, the shorter the focal distance.

(b) A plano-convex lens (fig. 179) has a plane surface and a convex surface. The plane surface is directed towards the light and does not contribute to the converging power of the lens.

(c) The *convexo-concave* or *meniscus converging* lens (fig. 179) possesses both a convex and a concave surface. The more powerful convex curve makes this a positive lens despite the fact that the concave surface tends to diverge the light, thus subtracting from the converging power of the lens. Meniscus lenses are mainly used for



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**Figure 79 – Comparative Focal Lengths of Elements in Compound Lenses**

spectacles because they permit undistorted vision through their margins as the eyes are rotated in their sockets.

(2) **CONCAVE LENSES.** Concave or divergent lenses (fig. 179) are thinner in the center than at the edges and will diverge light from distant sources and objects.

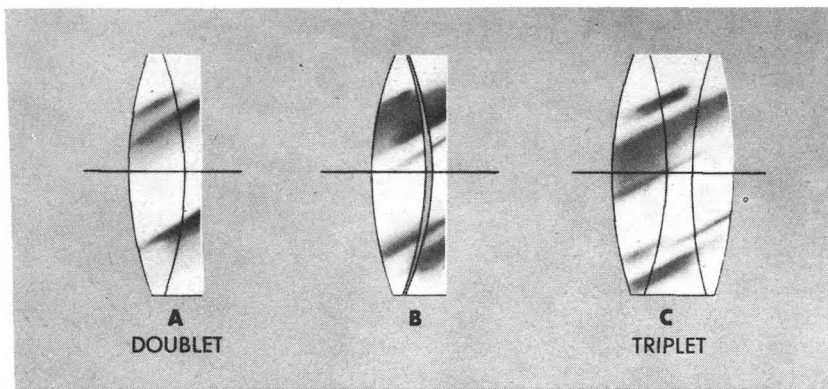
(a) One face of divergent lens may have a more powerful concave curvature (*double-concave*); one surface may be concave and the other plane (*plano-concave*); or one face may be concave while the other is convex (*concavo-convex* or *divergent meniscus*).

(b) The convex surfaces of either converging or diverging lenses of this type are often toward the light. The more powerful curve determines whether the lens is convergent or divergent.

**b. Compound Lenses.** As an optically perfect single lens cannot be produced, two, three, or more lenses ground from different types of optical glass are frequently combined as a unit to cancel aberrations or defects which are present in the single lens (see aberrations, ch. 2, sec. VII).

(1) The refractive power of a compound lens is less than that of the convex lens alone. For example, if a double-convex lens of crown glass is combined with a concavo-plano lens of flint glass, the latter would have little more than half the refractive power of the former, but sufficient dispersive power to neutralize the dispersion. The result would be that light passing through this compound lens would be brought to a practical focus at a point that would be about double the distance of the focal point of the crown lens alone (fig. 79).

(2) The elements are frequently cemented together with their optical axes in alignment. Two lenses may be cemented together as



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**Figure 80 – Types of Objectives**

a *doublet* or three may be cemented together as a *triplet*, or each lens of the unit may be mounted separately (fig. 80). The cementing of the contact surfaces is generally considered desirable because it helps to maintain the two elements in alinement under sharp blows, it aids cleanliness, and it decreases the loss of light through reflection at the two surfaces in contact.

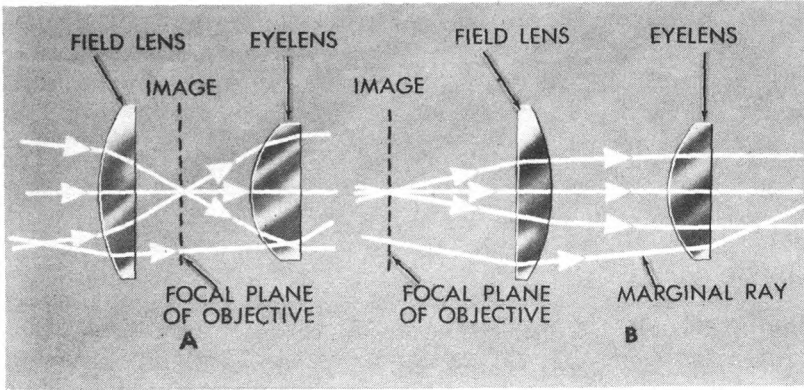
## 65. OBJECTIVES.

a. **General.** The lens nearest the object in any optical system of the refracting type is called the *objective*. Its function is to gather as much light as possible from the object and form a real image of that object. Objectives usually are of the compound type in order to reduce color and other aberrations to a minimum.

b. **Construction.** The majority of objectives are constructed of two elements, a double-convex converging lens of crown glass and a plano-concavo flint lens (A, fig. 80).

(1) When the elements of the objective are of large diameter, or when the faces of the elements are of different curvature, the elements are not cemented but are held in their correct relative positions in a cell by retaining and locking rings (B, fig. 80). This construction permits giving the inner surfaces of the two elements different values, and allows greater freedom in the correction of aberrations. An objective of this type is often called a *dialyte* or *Gauss objective*.

(2) Certain objectives are composed of three elements securely cemented together (C, fig. 80), or with two of the elements cemented and one mounted separately. Such objectives afford a total of six surfaces upon which the designer can secure the best possible correction for aberrations.



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**Figure 81 – Typical Light Paths Through Field Lens and Eyelens**

### c. Relation of Objective to Optical System.

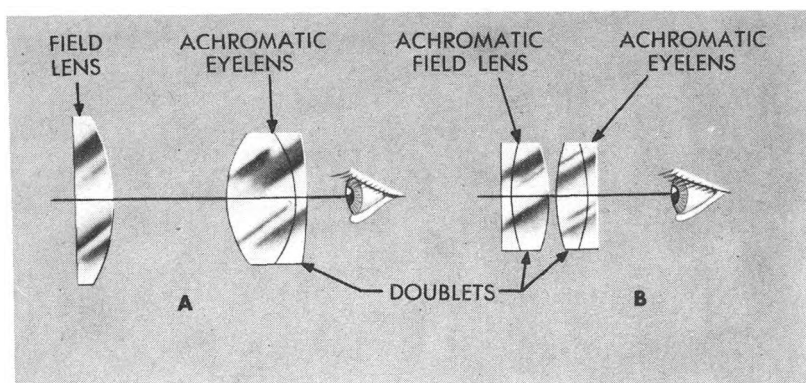
(1) The size of the objective affects the amount of magnification that can be used in the instrument. Only so much light can pass through a given objective. If the magnification were increased, that amount of light would be distributed over a larger image area and a dimmer image would result. The effective size to which an image may be magnified is, therefore, governed to a great extent by the size of the objective.

(2) Increasing the size of the objective beyond a certain point does not improve the brightness of the image appreciably because of the restriction imposed by the size of the pupil of the eye.

(3) Some fire control instruments, notably tank telescopes, have objectives which are smaller than the eyelenses of the instruments. Most instruments of this nature, however, have low magnification. Others sacrifice a certain amount of the light-gathering qualities of the larger objective for compactness of instrument.

## 66. EYEPieces.

a. The real image formed by the objective at its focus is small and generally is too close to the eye to be seen properly. If this image is moved far enough away from the eye to be seen, it will subtend too small an angle at the eye for visibility. Means must be provided to magnify the image and make it appear sufficiently distant from the eye (usually at infinity) to be clearly seen. This is accomplished by the eyepiece. The eyepiece may be considered a magnifying glass which enlarges the image produced by the objective (fig. 81). The eyepieces of modern fire control instruments generally consist of two or three lenses, one, two, or all three of which may be compound lenses.



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**Figure 82 — Types of Kellner and Plossl Eyepieces**

b. The lens of the eyepiece nearest the eye is called the *eyelens*. The eyelens does the actual magnifying of the image and can affect the quality of the image as seen by the eye. The lens in the eyepiece nearest the objective is called the *field lens*. The field lens gathers the light from the objective and converges it into the eyelens. If it were not for the field lens, much of the marginal light gathered by the objective would not be brought into the field of the eyelens, and the edge of the field of the latter would be dark (B, fig. 81). By collecting and converging light from the outer part of the field into the eyelens, the field lens helps produce a uniformly illuminated image.

c. There are two eyelenses in the optical systems of some instruments with variable magnification. One of these is mounted directly in front of the other and behind the field lens. The forward eyelens is called the *first eyelens*; and the eyelens nearest the eye, the *second eyelens* (A, fig. 85). The third element in the optical systems of certain three-element eyepieces is called the *center lens* or the *collective lens*. This is a convex or positive lens, serving as a supplementary field lens, which assists in collecting and bending field rays back into the eyelens, to prevent their loss and subsequent loss of field and illumination (B, fig. 85).

d. The objective takes parallel rays of light from a distant object and brings them to a focus, turning them into angular rays. The eyepiece takes these rays, which are diverging after having been brought to a focus, and converts them back into parallel rays and directs them into the eye. It forms an image at the point where the eye is placed when looking through the instrument. This point is known as the *exit pupil*.

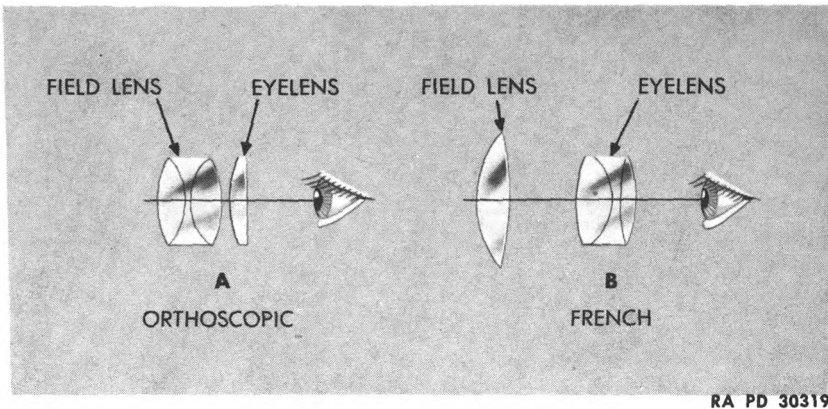


**Figure 83 — Orthoscopic Eyepieces**

e. Magnification by the eyelens or eyelenses may be fixed or variable, or there may be no magnification. Some instruments are provided with changeable eyepieces to secure different degrees of magnification. In other instruments, the relative positions of lenses not in the eyepiece are changed to effect changes in magnification.

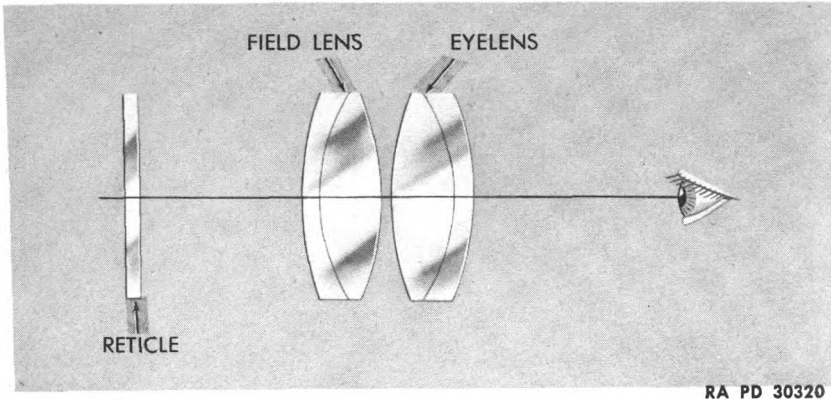
f. The field lens does not greatly affect the size of the image. Theoretically, it should be placed exactly in the focal plane of the real image, in which case it would have no effect on magnification. In practice, it is moved away from this point, usually back of it. In this location, dust on the field lens is not in the field of view while, at the same time, the field lens does exert some effect on magnification and the quality of the image. Other reasons for not placing the field lens in the focal plane are:

(1) This is the position normally occupied by the reticle in those instruments employing reticles.

(2) In this position, it is not practical to apply nonreflecting coating to the surfaces.

g. **Types of Eyepieces.** Types of eyepieces used in optical fire control instruments are discussed in the following subparagraphs. They represent general types rather than the specific eyepieces of instruments inasmuch as a specific type of eyepiece generally is modified to make it best suited for a particular instrument.

h. **Kellner and Plossl Eyepieces.** The Kellner eyepiece (fig. 82) consists of an eyelens and a field lens. It is corrected for color by the use of a doublet made up of a flint and a crown glass lens. An eyepiece employing a doublet for the eyelens or the field lens, and a single lens of plano-convex or double convex type for the other lens (A, fig. 82), is one of the more common designs used in fire control instruments. An eyepiece employing a doublet for each lens

**Figure 84 — Symmetrical Eyepiece**

(B, fig. 82) is known as a Plossl eyepiece. Some of the telescopes which use the Plossl eyepiece are listed below:

Elbow Telescope M17

Elbow Telescope M24

Elbow Telescope M26

Height Finder M1

1-meter Base Range Finder M1916

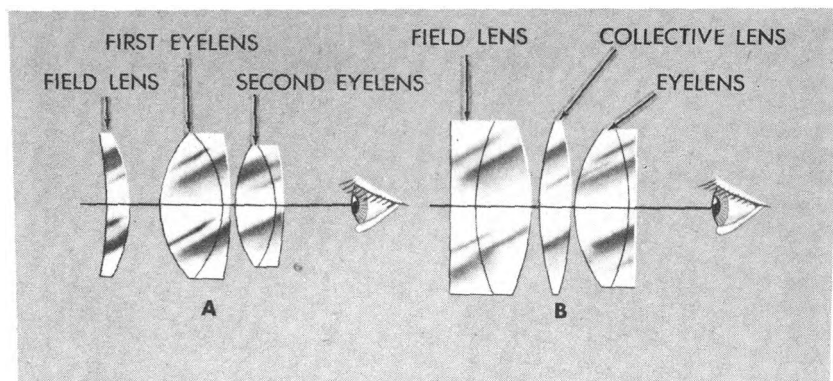
Panoramic Telescope M1

Telescope M60

i. **Orthoscopic Eyepiece.** The orthoscopic eyepiece (A, fig. 83) employs a three-component field lens and a single eyelens, usually of plano-convexo type. It is used on high-powered telescopes in which an eyepiece of very short focus is required. It is so named because of its freedom from distortion. An eyepiece design employing these elements in the reverse order is called the French eyepiece because it was generally indicated on French drawings furnished the United States of America during World War I (B, fig. 83).

j. **Symmetrical Eyepiece.** In symmetrical eyepiece (fig. 84), both the field lens and the eyelens are doublets. Eyepieces of this type have the advantage of comparatively great eye relief and large exit pupil; they do not afford great magnification. They are employed in telescopes which are mounted directly on a gun carriage to provide maximum relief between the eye of the gunner and the eyepiece when the weapon recoils.

k. **Eyepiece With Variable Magnification.** These eyepieces generally employ two eyelenses in addition to the field lens (A, fig. 85). Magnification is obtained by changing the distances between the elements of the erecting system of the telescope. A collective lens in the body of the instrument is often one of the elements of the optical system of such an instrument.



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**Figure 85 — Eyepieces With Two Eyelenses and With Collective Lens**

1. **Erffle Eyepiece.** This eyepiece includes a collective lens in the optical system of a three-element eyepiece (B, fig. 85). Such a lens tends to shorten the focal length of the eyepiece and to supplement the field lens in collecting and refracting field rays to improve the brightness of the field and provide a more uniformly illuminated image. A few of the telescopes using this eyepiece are:

Elbow Telescope M2

Panoramic Telescope M8

Panoramic Telescope M12

Telescope M31

## 67. PRISMS.

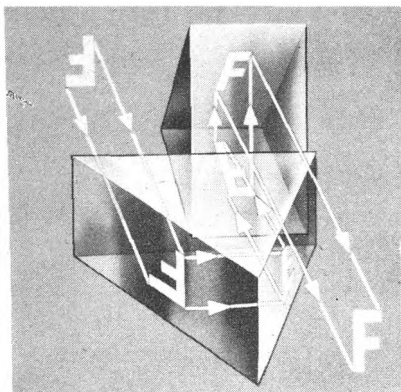
### a. General.

(1) In fire control instruments, it is frequently desirable to bend the rays of light through an angle in order to bring the eyepiece into a more convenient position, or to erect an image. Plane mirrors are sometimes used to change the angles of the light rays, but the silvered surfaces tend to tarnish and cause a loss of light which grows more serious as the instrument becomes older. A prism used for the same purpose can be mounted in a simpler and more permanent mount, the angles of its surfaces cannot be disturbed, and it can produce more numerous reflection paths than would be practical with mirrors.

(2) Optical prisms are blocks of glass of many shapes, especially designed and ground to permit them to perform their various functions. They are used singly or in pairs to change the direction of light from a few seconds of arc (measuring wedges) to as much as 360 degrees (Porro prism system).

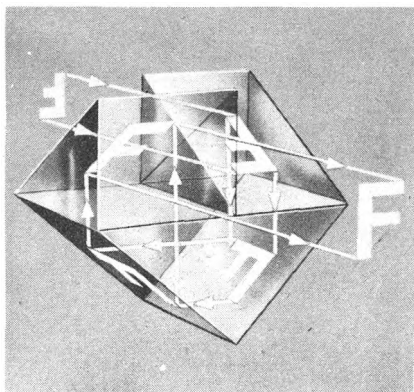
(3) When the incident rays strike the reflecting surface of a prism at an angle greater than the *critical angle* (par. 18) of the sub-





RA PD 30122

Figure 86 — Porro Prism Systems



RA PD 30123

Figure 87 — Abbe System

stance of which the prism is composed, the reflecting surface does not need to be silvered. This surface must be silvered if the incident rays strike it at an angle less than the critical angle.

**b. Right-angle Reflecting Prism.** Depending upon which reflecting surface is struck by the incident ray, the right-angle reflecting prism will bend the light rays through an angle of 90 degrees or 180 degrees. The manner in which this prism reflects rays through an angle of 90 degrees is illustrated and described in paragraph 18 f, and through an angle of 180 degrees, in paragraph 23 c. When used to reflect rays through an angle of 90 degrees, the rays are reflected only once with the result that the image is reverted. When used to reflect rays through an angle of 180 degrees, the rays are reflected twice and, while the image is inverted in the plane in which the reflection takes place, there is no reversion.

**c. Porro Prism Systems.**

(1) Each element of the Porro prism system is a right-angle reflecting prism placed to bend rays of light through an angle of 180 degrees. One element is arranged to bend the rays horizontally and the other to bend the rays vertically; one element reflects the rays into the other (fig. 86). As the image formed by a lens is inverted and normal, one element of the Porro prism system inverts this image from side to side while the other inverts it from top to bottom, producing a normal, erect image. The Porro prism system is used as the erecting system in many fire control instruments; it is commonly used in binoculars. The sharp corners of these prisms are removed, making the ends round. This reduces the weight and lessens the chance of breakage.

(2) A second type of Porro system, known as the Abbe system (fig. 87), is less commonly used because of difficulty of manufacture.

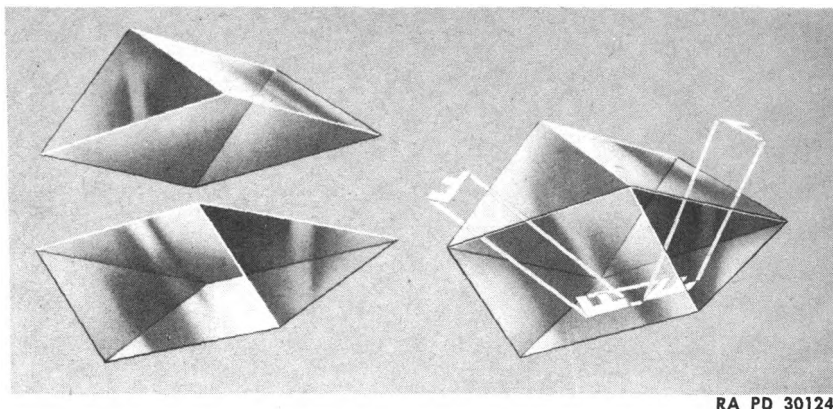


**Figure 88 — Amici or Roof-angle Prism**

It consists of a single prism which is three prisms in one. It is substantially the same in principle as the first type, but the reflections occur in different order.

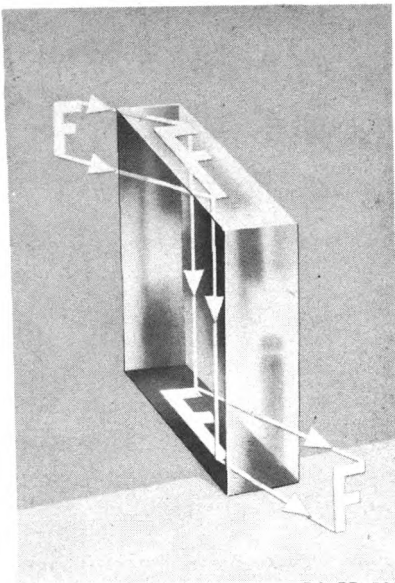
**d. Amici or Roof-angle Prism.**

(1) This is a one-piece prism which deviates the light through an angle of 90 degrees while, at the same time, inverting the image through two planes (fig. 88). It may be considered as made up of a right-angle reflecting prism with the hypotenuse face or base replaced by two faces inclined toward each other at an angle of 90 degrees. The latter two faces form the "roof" and give this prism its name. When inserted in the optical system of a telescope, it bends the light rays within the instrument through an angle of 90 degrees and also erects the image.

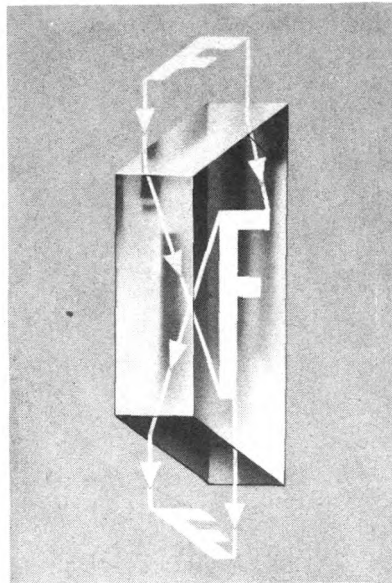
(2) When employed as the erecting prism of an elbow telescope, one of its uses, the light ray enters one short face (fig. 88) where it strikes the reflecting surface of one side of the roof. It is reflected to the other side of the roof where it is reflected outwardly at right angles to the direction in which it entered the prism. Usually, the parts of the prism not used by light rays are removed, affecting the appearance of the prism but not its fundamental shape or function.

(3) The Amici prism is compact and it transmits a great amount of light, but it is one of the most difficult of all prisms to manufacture because the angle between the two inclined faces of the roof cannot differ from 90 degrees by more than a few seconds if the prism is to function satisfactorily.

**e. Rhomboidal Prism.** The rhomboidal prism (fig. 89) may be considered as made up of two right-angle reflecting prisms built in one piece, or as a rectangular block of glass with the upper and lower faces cut to the same angle. When the upper and lower faces are



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**Figure 89 — Rhomboidal Prism**

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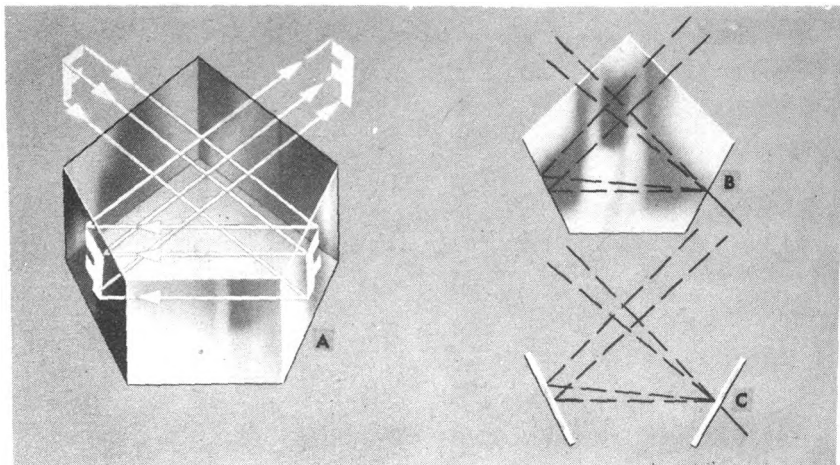
**Figure 90 — Dove (Rotating) Prism**

parallel and the front and rear faces are parallel, this prism does not invert or revert the image nor change the direction of the light rays, but displaces the light rays parallel to itself. This is due to double reflection without reversal of the direction of light. This result is obtained with mirrors in certain periscopes. Rhomboidal prisms are employed in height finders to shift the lines of sight to secure interpupillary distance adjustment.

**f. Rotating or Dove Prism.** The rotating or Dove prism (fig. 90) resembles the rhomboidal prism except that the angles of its ends are opposite to one another, but this prism serves an entirely different purpose. Light rays entering the upper face of the prism are reflected once against the longest face of the prism, after which they continue in the original direction out of the lower face. The image is inverted by the single reflection.

**g. Penta-prism or Five-sided Prism.**

(1) The penta-prism (fig. 91) reflects light rays through an angle of 90 degrees by two reflections. It does not invert or revert the image (the figure shows the front of the object and the rear of the image). Because of the arrangement of the two reflecting surfaces, slight movement of the prism does not affect the true right angle at which the light rays are reflected (B and C, fig. 91). This feature makes this prism useful in range finders where the angles of



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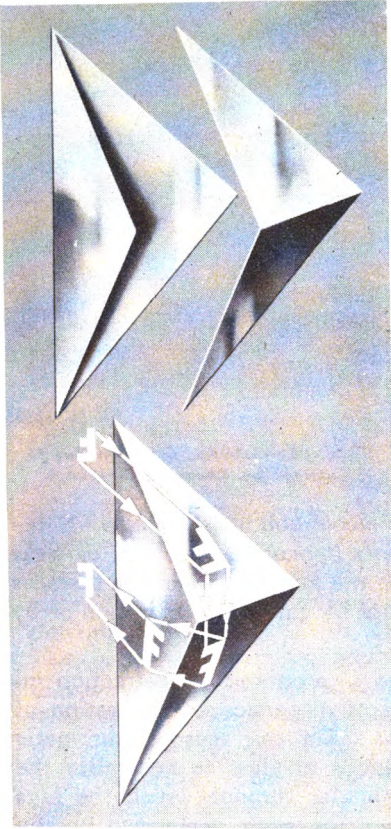
**Figure 91 — Penta Prism (Diagrams Show Same Effect Obtained With Mirrors)**

the rays must remain constant. (The angles measured by the range finder are so small that any deviation in the angles brought about by slight bending of the tube and consequent rotation of the prisms would be sufficient to impair the accuracy of the instrument.) It is necessary to silver the reflecting surfaces of the penta-prism as the rays strike the reflecting surfaces at angles less than the critical angle, and total reflection does not result.

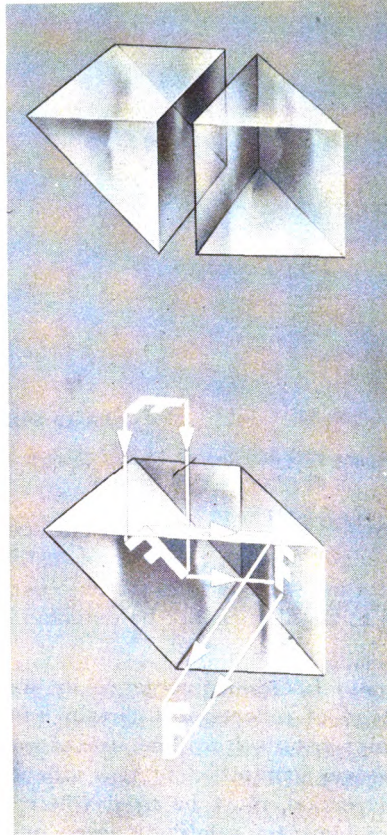
(2) In the long base height finders, the penta-prisms that would be required would be so large that it would be difficult to find blocks of glass sufficiently large and homogeneous for the construction of such prisms. Two mirrors are used to replace the two reflecting surfaces of a penta-prism (C, fig. 91). These mirrors are fastened in a rigid mount at precisely the same angles as the reflecting surfaces of a penta-prism of the same size, and produce the same effect. Temperature changes must be eliminated insofar as possible to hold the reflecting surfaces in the proper relation with one another.

**h. Triple Mirror.** The triple mirror (fig. 92) has four equal triangular faces, any three of which are reflecting surfaces. It may be considered as consisting of two triangular roofs, one above and one below, with the peaks of the roofs at right angles to one another. This prism has the unique property of deviating, through an angle of 180 degrees, any ray of light entering it. If the angles of this prism are accurately made, light will be returned along a course parallel to its original path no matter how the prism is turned, so long as it receives the incident light.

**i. Double Right-angle Prism.** The double right-angle prism consists of two right-angle prisms joined as shown in figure 93. This



RA PD 30128

**Figure 92 — Triple Mirror**

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**Figure 93 — Double Right-angle Prism**

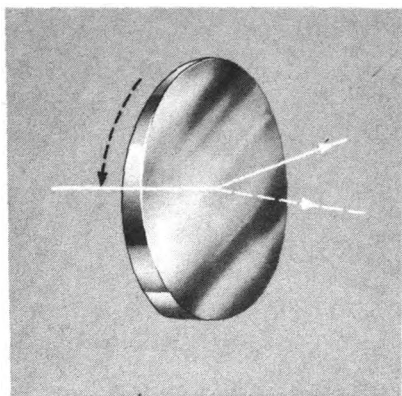
prism reflects light twice, the first time at right angles and the second time at right angles to the direction of the incident ray as well as to its first reflection. The image is not reverted.

## 68. WEDGES.

a. The optical wedges used in fire control instruments are prisms which divert the paths of light by refraction instead of by reflection. They are used where the angle of diversion required may be a matter of fractions of seconds of arc and it would not be practical to produce such slight diversions by means of reflecting surfaces. Wedges are used in the measurement systems of range and height finders and to correct or adjust the alinement of paths of light. They are of two general shapes, rectangular and round.

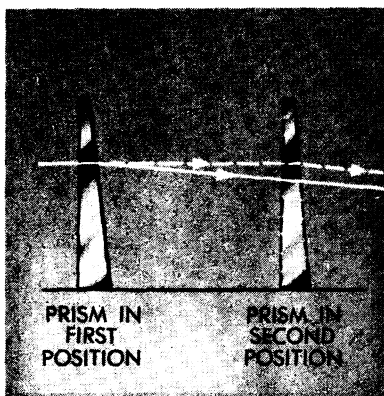
b. The angle at which a wedge will divert the path of light is dependent upon the relative slant of its two faces which are inclined





RA PD 30134

Figure 94 — Rotation of Wedge Changes Direction of Path of Light



RA PD 30135

Figure 95 — Extent of Deviation May Be Changed by Movement of Wedge

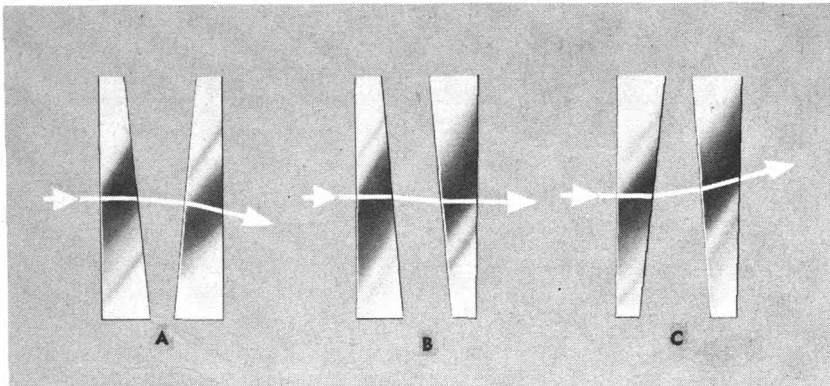
toward each other like the surfaces of a common house shingle. Some wedges used in fire control instruments appear to be plates or disks of glass with parallel surfaces because the angle between the surfaces is so slight it cannot be detected except by careful examination or by actual measurement.

c. Because divergence by wedges is produced by refraction instead of reflection, a certain amount of dispersion or separation of color results from the use of wedges. For this reason achromatic wedges, composed of two different kinds of glass to neutralize the dispersion, must be used where the angles through which the rays are bent are relatively large or where the work performed by the wedges is of the most exacting nature.

d. All wedges cause a certain deviation of the path of light. Instruments employing wedges are therefore designed so that the path of light entering the wedge has a certain amount of initial deviation, which is termed the *constant deviation*. Were it not for this factor, the wedge could be made only to increase the amount of deviation. The constant deviation makes it possible for the wedge to neutralize the path of light or divert it at a minus angle.

e. A wedge may be caused to change the direction of a path of light by rotation of the wedge (fig. 94). The extent to which a wedge may be made to divert the path of light may be varied by changing the position of the wedge with relation to the other elements of the optical system (fig. 95).

f. Another means of varying the deviation of a path of light is the use of pairs of wedges which are geared to rotate in opposite directions. The wedges of such a system, which may consist of two or four elements, are referred to as *rotating wedges* or *rotating compen-*



RA PD 30136

**Figure 96 — Principle of Rotating Measuring Wedges**

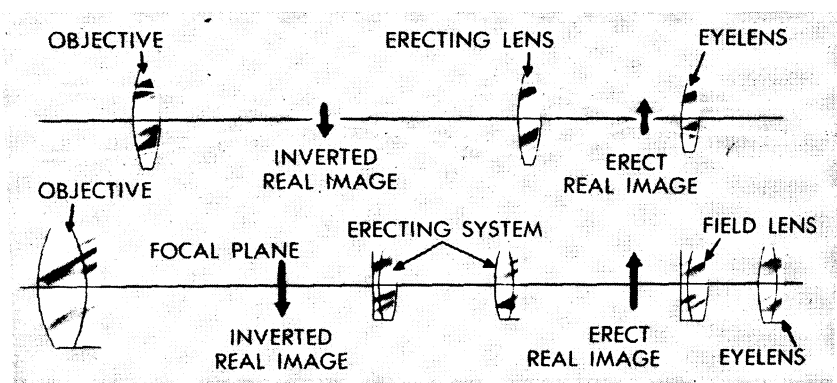
*sating* wedges. When the thicker edges of two of these wedges are together (A, fig. 96), they produce a deviation twice that of one wedge, and in the direction of the thicker edges of the wedges. When rotated until the thick edge of one wedge is toward the thin edge of the other (B, fig. 96), the wedges neutralize one another and the wedges produce no deviation. Intermediate positions cause a deviation which increases as the thick edge of one wedge rotates farther from the thin edge of the other. When both wedges are rotated through 180 degrees (C, fig. 96), the thick edges again are together and the wedges function as in A, figure 115, except in the opposite direction.

## 69. ERECTING SYSTEMS.

a. **Types.** Erecting systems are of two general types, lens and prism. While most lens erecting systems are of the same general design, differing only in the types of lenses used and the spacing of the elements, the prism erecting systems employ elements of a wide variety of shapes, causing the rays of light to be diverted in different paths in the different systems.

(1) A lens erecting system greatly increases the length of an instrument. It is often used where length in the optical system is a distinct advantage, as in periscopes. This system also is employed in instruments with variable magnification because different degrees of magnification can be obtained by changing the relative positions of the lenses.

(2) Where compactness of instrument is a desirable feature, a prism erecting system is used. Such a system may consist of a single element, or several. The great reduction of length resulting from the use of a prism system is due to the doubling back of the path of light.



RA PD 30130

Figure 97 - Lens Erecting Systems

The prism erecting systems in most general use employ Porro and Abbe prisms, the Amici or roof prism, the Dove or rotating prism, and single and double right-angle prisms.

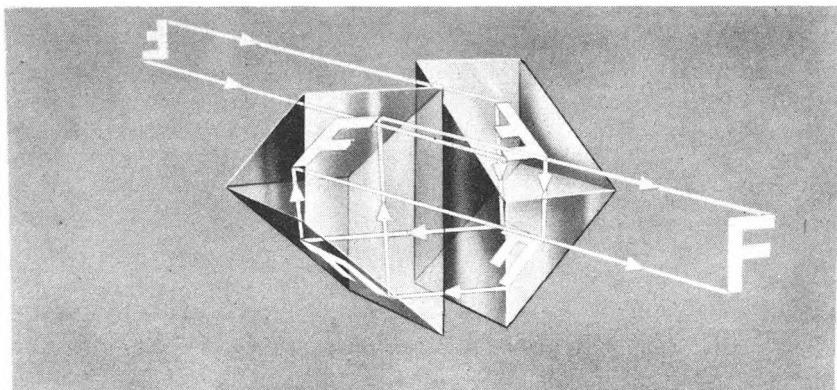
#### b. Lens Erecting Systems.

(1) The simplest form of lens erecting system places a second convex or converging lens in the proper position to pick up the inverted image formed by the objective, and form a second erect image which is magnified by the eyepiece (upper, fig. 97). In fire control instruments, a lens erecting system of two, and sometimes three, lenses is substituted for the single erecting lens (lower, fig. 97). The entire lens erecting system functions as a single lens.

(2) In a two-element lens erecting system, both lenses usually are of compound (achromatic) type. In a three-element system, the third lens is of plano-convex or double-convex type and serves as a collective lens. It converges the light rays of the image formed by the objective so they will pass through the erecting lenses. It increases the field of view and brightness of image for a given diameter of the lenses of the erecting system. Inasmuch as the collective lens is sometimes placed at the point where the image of the objective lens is formed, and a reticle must be placed at this same point, the reticle markings are simply engraved on the flat face of the plano-convex lens used as the collective lens.

(3) According to the placement of the erecting lenses, a lens erecting system may increase or decrease the magnifying power of the instrument, or it may not affect magnification. Moving these lenses closer to the focal point of the objective lens and farther from the eyepiece increases the magnification, but cuts down the field of





RA PD 30131

**Figure 98 — Erecting System Using Two Double Right-angle Prisms**

view. When these lenses are located at equal distances from the focal points of the objective and the eyepiece, there is no magnification. This method of changing the degree of magnification is employed in instruments of variable power.

c. **Prism Erecting Systems.** Prism erecting systems function by internal reflection. As a single reflection will cause reversion of an image, reflections must be in pairs to overcome this condition. If the path of light is to continue in an unchanged direction, a total of four reflections is required, two to revert the image and two to invert it (inversion in two planes). The use of prisms does not alter the magnification of the instrument.

(1) **PORRO ERECTING SYSTEM.** This system is employed in prism binoculars and in a number of telescopes. It tends to decrease curvature of the field, and its use is particularly advantageous when a compact instrument having a large field of view is desired as is the case in observation telescopes. This system is not well suited to telescopes which are to be mounted on gun carriages as the prisms are of awkward shape and it is difficult to clamp them so tightly that they will not shift their positions when the gun is fired.

(2) **ABBE PRISM SYSTEM.** This erecting system (fig. 98) employs two double right-angle prisms (fig. 93). The two prisms are assembled in the instrument in the same general form as the Abbe prism (fig. 87), except that the two prisms are not joined, a slight amount of space being left between them. The travel of the light rays through this erecting system is shown in figure 98.

(3) **AMICI OR ROOF PRISM.** When used in an elbow telescope, this single prism (fig. 88) serves as an erecting system as well as a right-angle prism. By its use, the light rays are diverted through the

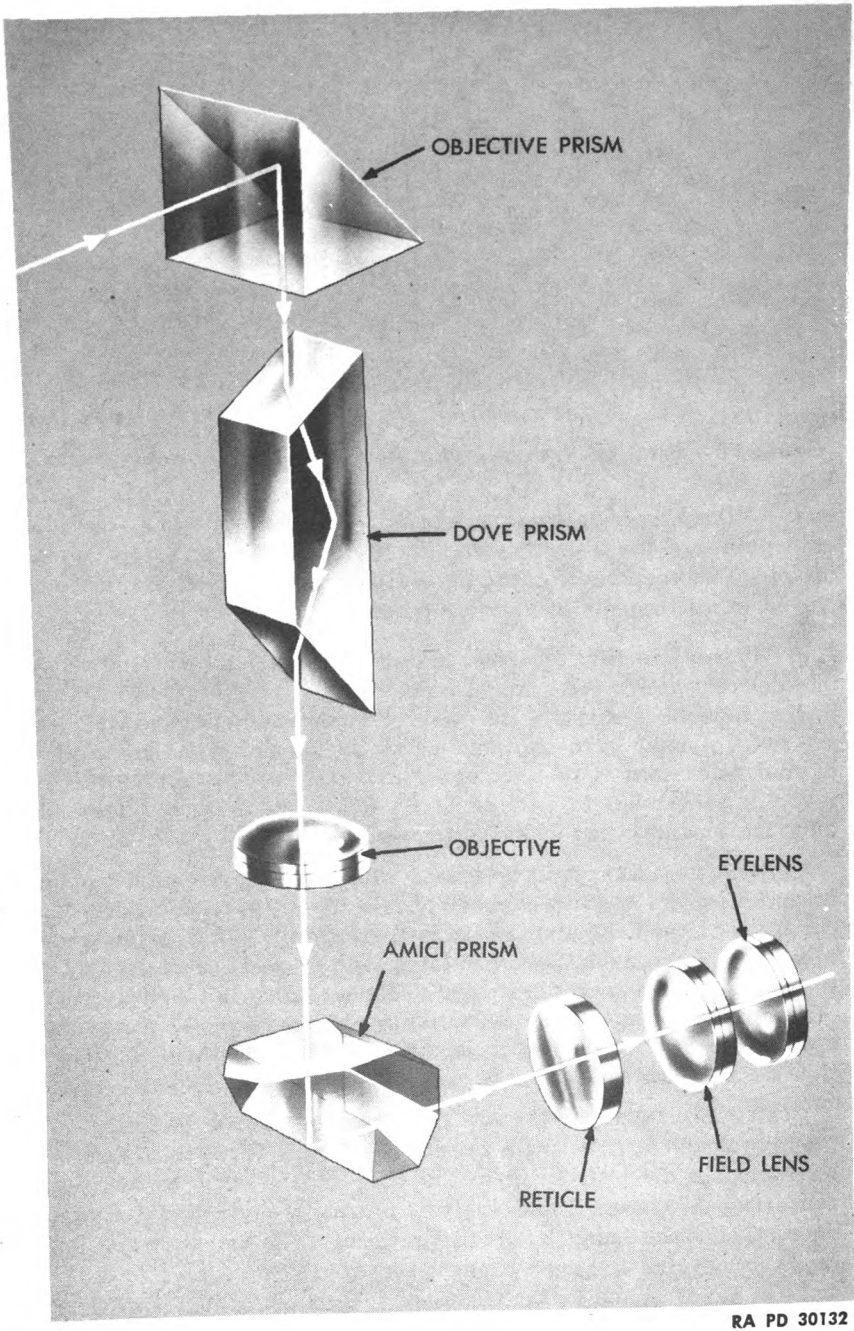
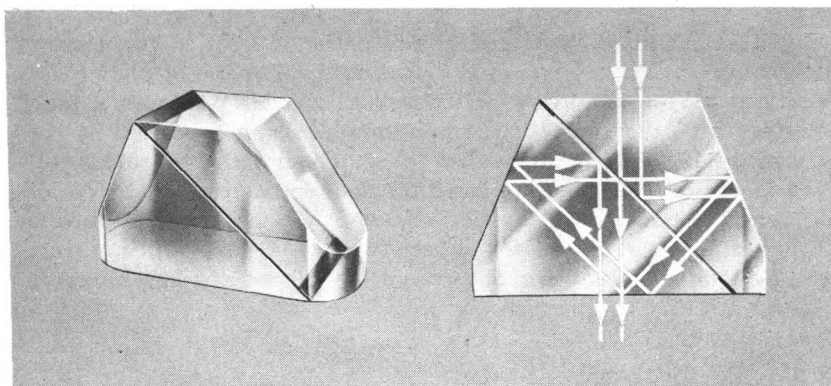


Figure 99 – Optical System of Panoramic Telescopes



RA PD 30133

**Figure 100 — Erecting Prism Assembly**

right angle of the telescope and the erection of the image is secured by reflection on two of its surfaces. It can be mounted securely and thus is suitable for telescopes which are mounted on gun carriages. Combined with a rotating prism and a right-angle prism, it is used in the erecting system of panoramic telescopes.

(4) **DOVE OR ROTATING PRISM.** The Dove or rotating prism (fig. 90) is the means by which the image in a panoramic telescope is caused to remain erect as the head of the instrument is rotated. The entering rays are diverted downward but are reverted by a right-angle prism in the upper head of the instrument. This prism is called the *objective prism*. The reverting effect of the objective prism is neutralized and the light rays are kept in alignment by a *dove or rotating prism*. If the dove or rotating prism were to be fixed in the instrument and the objective prism were to be rotated in azimuth to the side or rear, the image viewed through the instrument would rotate until it became inverted. This difficulty is overcome by connecting the rotating prism to the objective prism with gearing which causes it to revolve with one-half the speed of the objective prism. This serves to keep the image in a vertical position regardless of the direction in which the upper head of the instrument is turned (fig. 98).

(5) **ERECTING PRISM ASSEMBLY.** The erecting prism assembly used in Panoramic Telescope M8 consists of two prisms separated at an angle of 45 degrees. Light rays entering this prism assembly are reflected five times before emerging (fig. 100); twice in one element and three times in the other. The incident rays and the emergent rays are in alignment and travel in the same direction. This assembly brings about an odd number of reflections and neutralizes the inversion caused by the objective prism.

## 70. MIRRORS.

a. The mirrors used to reflect the paths of light in fire control instruments are not the common household type made of plate glass. The back reflecting surface on household mirrors produces a faint reflection from the glass surface in addition to that produced by the silvered back. To eliminate this "ghost image," the reflecting surfaces of optical mirrors are placed on their front faces. Mirrors of this type are termed *first surface mirrors*. The reflecting surface is a thin film of metal chosen for its resistance to tarnish. Such mirrors must be handled carefully as they can easily be scratched and become useless until they can be resilvered.

## 71. RETICLES.

a. Reticles are used in fire control instruments for superimposing a predetermined pattern of range and deflection graduations on a target. A simple reticle may consist of two intersecting lines. The line of sight through their intersection is in the center of the field of view, and represents the axis of the bore of the weapon.

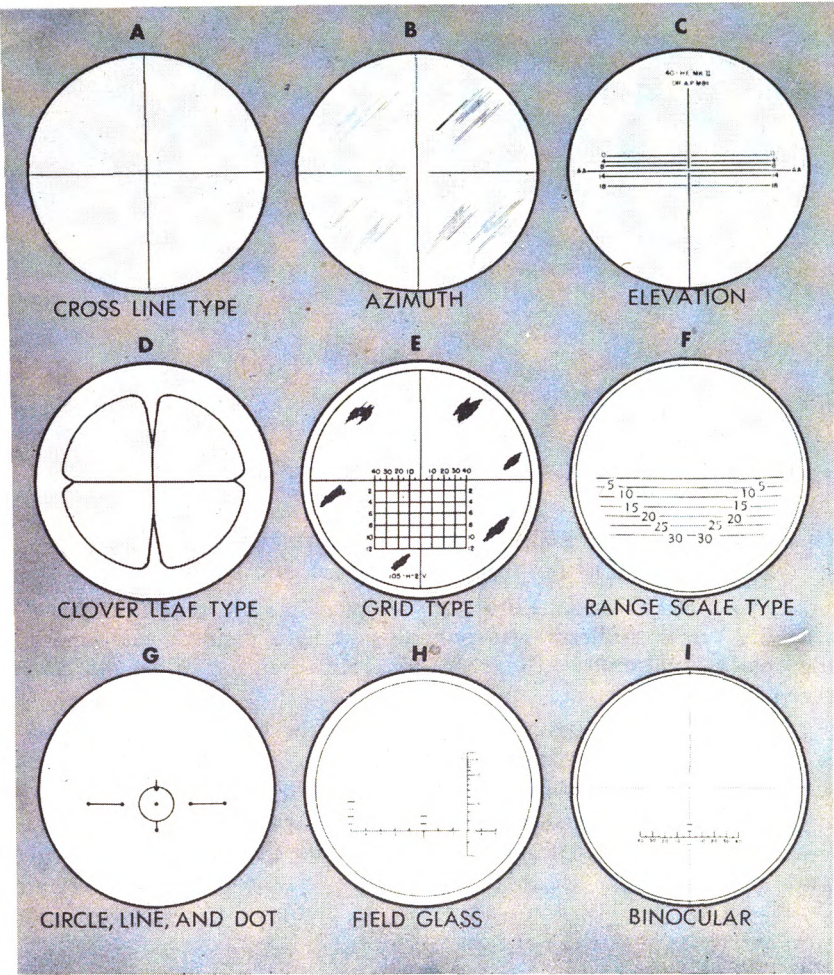
b. The majority of reticles are glass disks with plane parallel surfaces. Appropriate markings are engraved or etched on one of the surfaces. In some cases, a plano-convex lens is required at the point where the reticle would be mounted. In such cases, the markings are engraved on the plane surface of the lens. The cross lines of some instruments are strands of fine wire.

c. The reticle is placed in the instrument in the focal plane of the objective. With a lens erecting system, the reticle may be placed at the front or rear of the erecting system, or reticles may be placed at both points. The preferable position with this type of erecting system is in front of the system, as the objective and reticle then form a unit, and any shift of the erecting system does not disturb the alinement of these elements. With a prism erecting system, the reticle is usually placed in back of the erecting system.

d. There are many different types of reticle patterns (fig. 101) designed for different purposes. The reticle of an instrument designed for use on a particular weapon, when used with specific ammunition, is identified by a group of small figures and letters which appear near the bottom or top of the field of view (C and E, fig. 101). These figures and letters may be *Firing Table numbers* or *F. T. numbers*, to indicate the Firing Table used in designing the reticle, or may be other characteristic identification information.

## 72. DIAPHRAGMS AND FIELD STOPS.

a. Diaphragms are rings of opaque material, placed in an optical system so that light passes through their centers. As their apertures limit the field of view, they are sometimes called *field stops*. When placed between the objective and the erecting system or between the



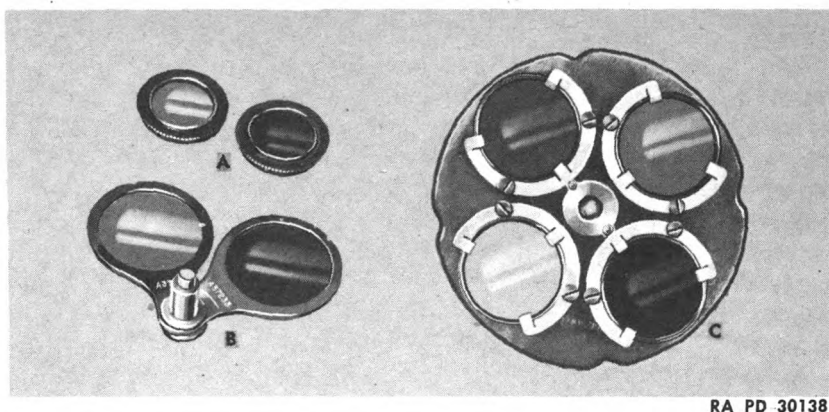
RA PD 30137  
**Figure 101 — Representative Types of Reticle Patterns**

erecting system and the eyepiece, or in both of these positions, they eliminate marginal rays which would otherwise cause glare by reflecting from the inside walls. When placed around the edges of lenses or within lens systems, they prevent rays from passing through the margins of the lenses and causing aberrations.

**73. FILTERS.**

a. **General.** *Filters* or *ray filters* are colored glass disks with plane, parallel surfaces. They are placed in the path of light through the optical system of a fire control instrument to reduce glare and light intensities. They are provided as separate elements which may





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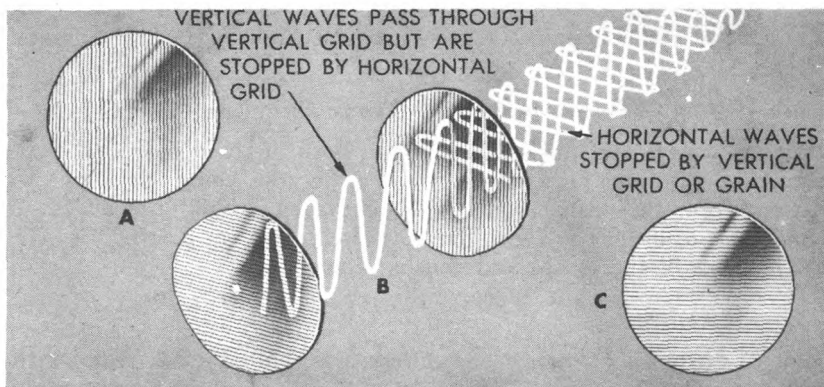
**Figure 102 – Types of Ray Filter Mountings**

be attached and detached (A, fig. 102) or are mounted so they may be placed in or out of position as desired (B and C, fig. 102).

**b. Colored Filters.** Filters of various colors are used to improve visibility under different atmospheric and light conditions. Among the colors of filters used are: smoke, yellow, amber, blue, red, and greenish-yellow.

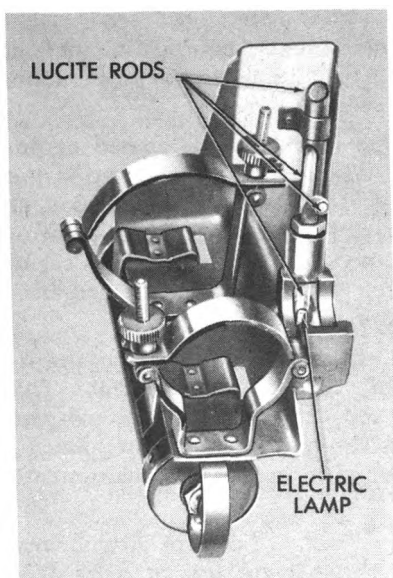
(1) The smoke (neutral) filter reduces the intensity of light and is effective when observing against or in close vicinity of the sun or a searchlight; usually it is too dark for other purposes.

(2) The yellow and amber are used to protect the eyes from the reflection of sunlight on water and other general conditions of glare.

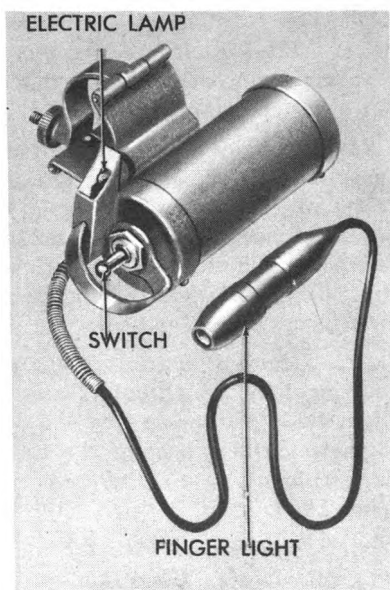


RA PD 30139

**Figure 103 – Principle of Polarization of Light**



RA PD 30144

**Figure 104 — Instrument Light M5 for Panoramic Telescope M6**

RA PD 30145

**Figure 105 — Instrument Light M1 for BC Telescope M1915A1**

(3) The amber and red filters are usually employed under various conditions of fog and ground haze. Red filters are also used in observing tracer fire.

(4) The blue filter is helpful in detecting the outlines of camouflaged objects.

(5) The greenish-yellow filter is intended to serve the purpose of both smoke and amber.

#### **c. Polarizing Filters.**

(1) Polarizing filters do not change the color of objects but merely decrease light intensity. When mounted in pairs, they can be used to provide continuous control of light intensity.

(2) Light polarizing substances can be considered as being made up of parallel bars or grain (A and C, fig. 103). Light vibrates in waves with the crests of the waves in all directions. A polarizing substance, placed in the path of the light, permits waves vibrating parallel to the direction of the waves or grain to pass through; waves vibrating at right angles to the bars or grain are stopped (B, fig. 103). By eliminating a portion of the light, the intensity of the light is decreased. When two polarizing substances are held with the grain of one at right angles to that of the other, no light passes through. By shifting the substances to intermediate angles, light at different degrees of intensity is permitted to pass through.

## 74. LIGHTING.

a. The reticles of fire control instruments require illumination, for night operation and under certain conditions for day operation, in order that their markings may be seen clearly.

b. Reticles are edge-lighted. The markings are etched or engraved into the surface of the glass. When light is introduced at the edge of the reticle, it travels through the glass and is diffused at these etched or engraved marks, illuminating them. Light is introduced at the edges of the reticles through small glass windows set in openings in the body of the instrument. At night, tiny shielded electric lamps are placed over the windows.

c. Lucite is a transparent plastic having the property of transmitting light which enters one end of a rod of this material. The light travels from end to end of the rod with little loss through the outside surface, despite the fact that the rod may be bent. Lucite is employed in the lighting systems of a number of instruments (fig. 104).

d. Instrument lights for the majority of fire control instruments are detachable. They consist of a container for one or more dry-cell batteries, a light switch which is sometimes combined with a rheostat, a clamping arrangement, and a miniature electric bulb with facilities for directing the illumination to one or more points on the instrument (fig. 104). Some systems have an additional "finger light" (fig. 105) to permit directing light to any part of the instrument.

## Section II

## COATED OPTICS

## 75. INTRODUCTION.

a. Whenever light strikes an ordinary glass surface, most of the light is transmitted through the glass and undergoes refraction. However, even under the most favorable conditions, about 4 to 6 percent of the light is lost by reflection from the surface. This loss takes place when light passes from glass to air as well as when light passes from air to glass.

b. This condition occurs at each optical surface of the majority of the elements in a fire control instrument. For example, in a straight telescope with 6 optical elements, there are 12 surfaces at which there is reflection and loss of light. Consequently, if each surface transmits 96 percent of the light which it receives, only about 60 percent of the light which enters the telescope is transmitted to the eye; the remaining 40 percent is lost by reflection and absorption from the surfaces of the various elements. The result is that the



image becomes dimmer; the stray reflections produce glare which reduces contrast, and "ghost images" are produced when viewing bright objects at night.

c. A process has been developed for coating the air-to-glass surfaces of optical elements with a very thin film of transparent substance. The coating reduces the loss of light from each optical surface to about 1 percent, resulting in a corresponding increase in the amount of light transmitted through the element. Optical elements so treated are termed *coated optics*.

d. A number of types of coating have been tested and applied to optical elements. Some have proved too soft to stand up under handling in normal use and service. The present coating consists of magnesium fluoride applied in films of thickness of one-quarter wave length of light. The coating is applied by an evaporation method in vacuum. The coating is durable enough to permit handling during assembly and disassembly and to withstand careful cleaning.

e. The main advantages of coating are:

(1) **INCREASED LIGHT TRANSMISSION.** When all the elements of a straight telescope are coated, except the reticle and filters, there is approximately 90 percent transmission of light instead of 60 percent, or half again as much light as would pass through the instrument were its optics uncoated. This improvement will result in a brighter image at times when light is scarce. It will be most obvious at dawn, dusk, or at night; in other words, at times of poor visibility. Targets are visible from  $\frac{1}{4}$  to  $\frac{1}{2}$  hour longer at dusk and at dawn. The range of vision at night is increased approximately 20 percent for standard binoculars.

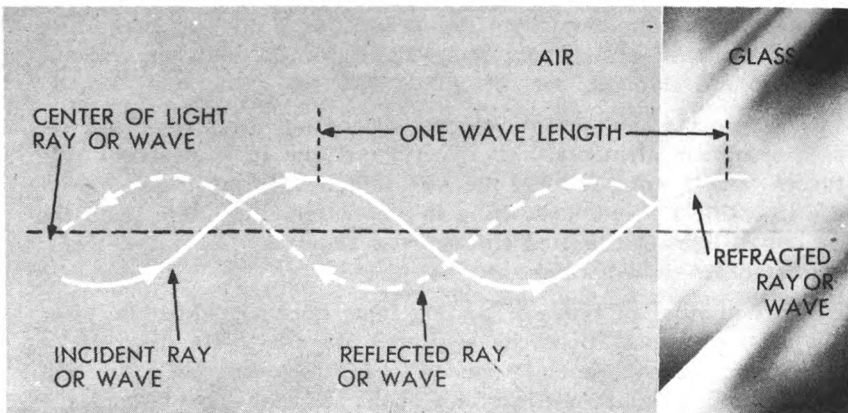
(2) **REDUCTION OF HAZE.** Light reflected from the surfaces of optical components in an instrument tends to throw a veil of stray light over the focal plane. Coating will reduce these internal reflections. Better contrast of the image will be the result.

(3) **REDUCTION OF GHOST IMAGES.** Internal reflections sometimes form an image or series of images which are slightly out of focus and not quite as bright as the image of focus. These ghost images are very distractive for proper aiming. Coating will greatly reduce the formation of ghost images.

(4) **REDUCTION OF FRONT SURFACE REFLECTIONS.** Reflections from the front surface of observation instruments are very noticeable at night and might give the observer's position away. By reducing reflections by means of coating, this danger is reduced.

## 76. THEORY.

a. Consider a tiny portion of a light ray, so highly magnified as to show its wave structure. A ray of light striking an uncoated glass surface could then be pictured as a wavy line as shown in figure 106.

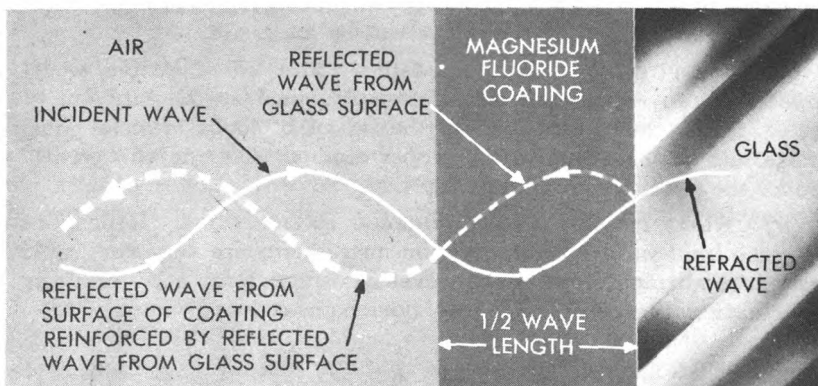


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Figure 106 — Light Ray Striking Uncoated Surface

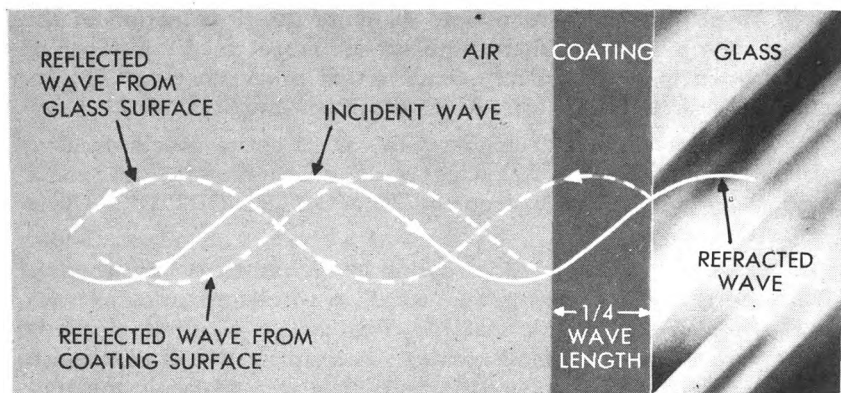
b. If a thin film of transparent substance were placed on the glass, there would be two surfaces from which the wave would be reflected. If this film were one-half as thick as a wave length of light, the reflected waves from the two surfaces would follow the same paths (fig. 107). In doing so they would reinforce each other, resulting in the maximum amount of light being reflected and the minimum amount of light being transmitted through the surfaces. This condition would be desirable in a reflector, but undesirable in a lens.

c. If, however, the film were only one-quarter of a wave length in thickness, the reflected waves would follow paths which would cause them to interfere with each other, and the reflected waves would cancel each other (fig. 108). The radiant energy, which is



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Figure 107 — Light Ray Striking Coated Surface (Coating One-half Wave Length in Thickness)



RA PD 30148

**Figure 108 — Light Ray Striking Coated Surface (Coating One-quarter Wave Length in Thickness)**

light, is not lost when the reflected waves are canceled; instead, this energy is contributed to the refracted light.

d. Since the wave length is different for each different color of light, one color must be selected to determine how thick the coating shall be. Green light, with a wave length of 20 millionths of an inch, is the logical color to use since it is in the middle of the visible spectrum. This color is in the brightest region and contributes most to vision. The thickness of the coating, therefore, should be  $\frac{1}{4}$  of 20 millionths of an inch, or equal to 5 millionths of an inch. Reflection of the colors at the extreme ends of the spectrum (red and violet) is not eliminated. Therefore, light reflected from a coated optical element appears purplish, similar to a mixture of red and violet.

e. Another useful application of magnesium fluoride coatings is on front surface aluminized mirrors used in optical instruments. In this case, a film thickness of one-half wave length causes reflected waves to reinforce each other (fig. 107). Such coatings also may be applied to front surface silvered mirrors. An aluminum or silver surface coated in this manner is no longer soft and easily scratched, but becomes harder and more durable and may be cleaned like other optical elements.

## 77. IDENTIFICATION.

a. Whether or not an instrument is fitted with coated optics can be detected readily by holding the instrument at an angle to a source of light and observing the reflections from the eyepiece and objective ends. If the optical elements in the instrument are coated, the reflection of light will have a distinctive purplish tinge. Under certain conditions, the faces of the lenses may appear to have a dull film or *patina*.

*Optical Components, Coated Optics, and Construction Features*

b. An alternative method is to compare the illumination of the field of view of an instrument with an equivalent model number or series known to have optical elements that are uncoated. The instrument with coated optics will have a much brighter field.

c. All fire control instruments with coated optics bear a decalcomania transfer with the following wording on either a green or a black background: "This Instrument Has 'COATED OPTICS'. Clean Lenses Carefully."

d. The magnesium fluoride coating is referred to as *hard coating*. There are a few instruments in the field with elements coated with what is referred to as *soft coating*. The coating on these elements is not as durable as the hard coating. A simple test will distinguish a hard coating from a soft coating. With a soft rubber eraser, rub the coated element near the edge so as not to impair the usefulness of the element. About 20 strokes will remove a soft coating, but hard coating will not be affected.

## 78. SERVICEABILITY.

a. Hard coating films on coated optics are tough and durable. They are insoluble in water, are not affected by oil and alcohol, and salt water will not harm them if cleaned off promptly. The coat will withstand temperatures from  $-60^{\circ}\text{F}$  to  $+200^{\circ}\text{F}$ . They are specified to withstand a rubbing of a  $\frac{3}{8}$ -inch pad of dry cotton, exerting a force of 1 pound rubbed in any direction 50 times. However, the effectiveness of the coating may be completely destroyed by carelessness, ignorance, or rough treatment.

b. Scratches tend to lower the quality of the lens. Wearing down of the film due to repeated cleaning is not harmful to the element itself, but a reduction in thickness of the film much below one-quarter of a wave length reduces its efficiency as a coated optical element. Partial or complete removal of the coating does not make the optical element useless, but merely partly or wholly takes away the benefit of the coating, leaving the element as if it had not been coated in the first place. It is important, therefore, that remnants of a partly deteriorated coating should not be removed, since even a partially coated lens will be more effective than an uncoated one.

c. Coated optics slowly deteriorate under fingerprints and the prolonged action of atmospheric dust and moisture, as well as salt water. Instruments containing coated optics should be well sealed. Exceptional precautions must be taken to prevent sealing and cementing compounds from getting on the coated surfaces of lenses. The removal of such compounds undoubtedly would result in injury to the coated surfaces.

d. Every precaution should be taken to prevent inexperienced personnel from misunderstanding the function of the coating and attempting to remove it.

## Section III

## GENERAL CONSTRUCTION FEATURES

## 79. LENS CELLS, SEPARATORS, AND RINGS.

a. A *lens cell* (fig. 109) is a tubular mounting or frame made of metal, plastic, or rubber which holds a lens or a number of lenses in the proper position within an optical instrument. The lens is usually secured into the cell by a lens retainer ring or by turning over a thinly feathered edge of the cell (burnishing). When two or more lenses are mounted in a cell, the different elements are maintained at the proper distance from one another by spacers or separators. The cell mounting permits the entire assembly to be handled and mounted as a unit.

b. *Separators* or *spacers* are smooth or threaded tubular sections which separate or space the elements of a lens system in the proper relation with one another (fig. 109). Adjoining faces are usually beveled to fit the faces of lenses snugly. *Lens retaining rings* are threaded about their outer diameters and are screwed in behind lenses to secure the lenses to their cells. An *adapter* may be used to mount an element or part of smaller diameter into a part of the instrument body which is of larger diameter.

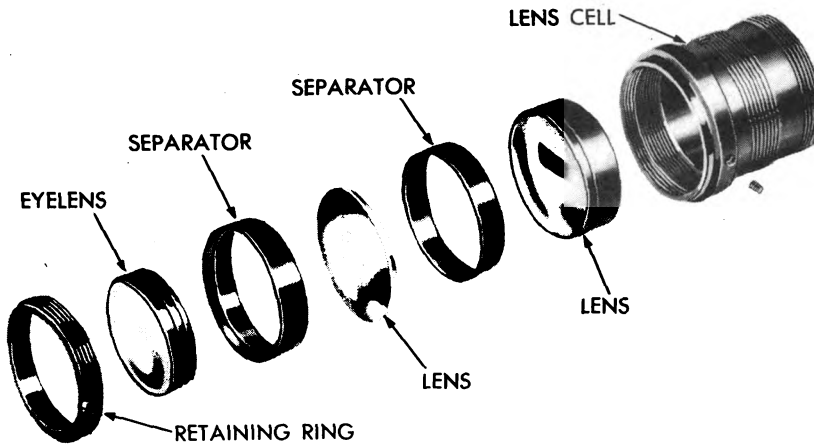
## 80. CENTERING DEVICES.

a. Light always bends toward the thickest part of a lens or prism. When the center of such a lens is moved, it can be made to cause the light to be bent in the desired direction. Movement of the center of the objective is accomplished by mounting it in a pair of eccentric rings (fig. 110). By rotating the objective about in the inner ring or by rotating the inner ring about in the outer ring, the axis of the objective may be moved to any point in a relatively large area. When properly positioned, the rings may be locked in position. Skill is required to set the rings in the proper manner.

b. Prisms are often placed in mountings designed to hold them firmly and yet afford movement for exact adjustment. Screws bear upon two faces of the prism to lock it in place. By letting out on one screw and taking up on the other, the prism may be positioned exactly. Extremely fine adjustments can be made.

## 81. EYESHIELDS.

a. *Eyeshields* or *eyeguards* are fitted to fire control instruments to maintain proper eye distance and to protect the eyes of the observer from stray light, wind, and injury due to the shock of gun fire or similar disturbances. Eyeshields are made of rubber, plastic,



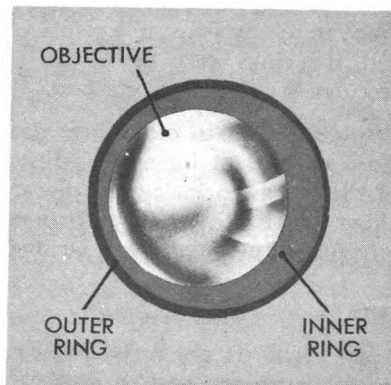
RA PD 30149

**Figure 109 — Lens Cell, Separators, Lenses, and Retainer Ring**

and metal, but only those made of soft rubber can most effectively meet all of these requirements.

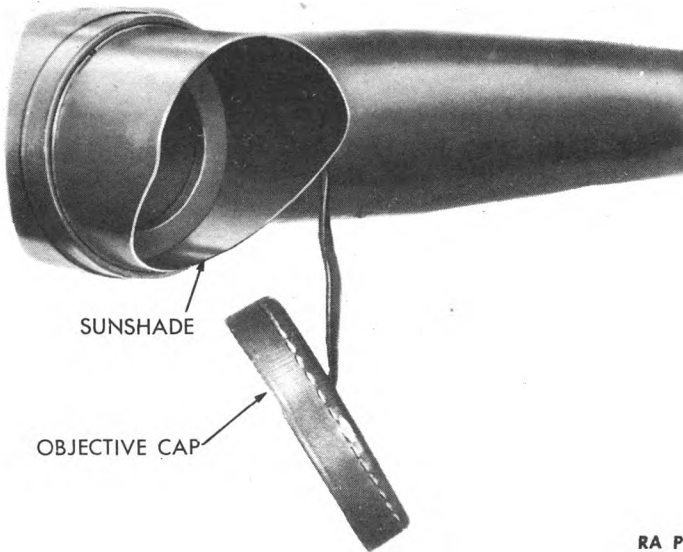
## 82. SUNSHADES AND OBJECTIVE CAPS.

a. *Sunshades* are tubular sections of metal, usually with the lower portion cut away, which are fitted into slots around the objectives of many instruments to protect against rain and the direct rays of the sun (fig. 111). They not only reduce glare which would be caused by sunlight striking the outer face of the objective, but they protect from extreme heat the canada balsam used to cement the elements of the objective.



RA PD 30150

**Figure 110 — Eccentric Objective Mounting**



RA PD 30152

**Figure 111 – Sunshade and Objective Cap**

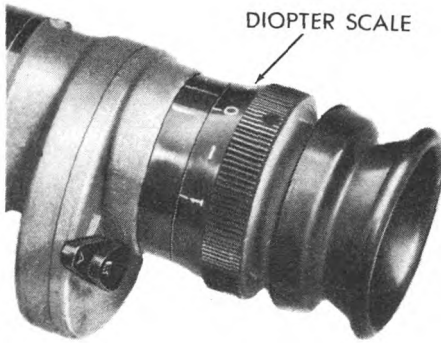
b. *Objective caps* (fig. 111) are leather covers which are fitted over either the sunshade or the objective end of the instrument to protect the objective when the instrument is not in use. The caps are usually attached to the instrument by strips of leather to prevent loss.

### 83. FOCUSING DEVICES.

a. The distance between the reticle and the eyepiece must be adjusted to the observer's eye so that the reticle and image of the object will be sharply defined, and to eliminate eye fatigue. To provide this adjustment, the two or more lenses of the eyepiece are mounted in a single tube or lens cell and its distance from the reticle (and the focal plane of the objective) can be adjusted by a rack and pinion by a simple draw tube, or by rotating the entire eyepiece by means of the *diopter scale* (fig. 112), causing it to screw in or out. This is referred to as the diopter movement. The knurled ring of the "screw out" adjustment type is provided with a scale reading in diopters by which this adjustment can be made directly, if the correction required by the eye is known.

### 84. OPTICAL BARS.

a. In a range or height finder the angles of the lines of sight from both ends of the instrument are employed to determine the range. Heat and cold cause unequal expansion and contraction of

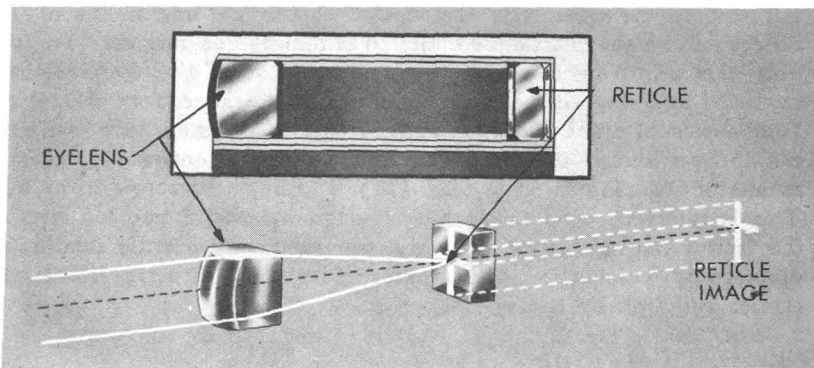


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**Figure 112 – Diopter Scale**

metal parts, disturbing the angular alinement of elements mounted on or in them. The extreme lengths of the large range and height finders would tend to emphasize the deviation caused by any mis-alinement if special measures were not taken to keep the optical systems stable and in perfect alinement.

b. One of these measures consists of mounting the most sensitive parts of the instrument in a metal tube known as the *optical bar*. The optical bar is made of specially treated steel with a low coefficient of expansion. It is perfectly balanced and is supported by the inner or main tube of the instrument in such a manner that the outer tube may expand or contract without affecting the alinement of the inner tube and optical bar. In addition, the instrument is insulated to reduce temperature changes to a minimum.



RA PD 30155

**Figure 113 – Collimator – Optical System and Optical Diagram**



**85. COLLIMATORS.**

a. The collimator (fig. 113) is an ingenious and relatively inexpensive type of sighting device. The collimator is inferior to the telescope in effectiveness or convenience of operation, but its simplicity, ruggedness, and low cost make it particularly desirable as a sighting device for mortars.

b. The principle of the collimator is that a reticle, fairly close to the observer, can be optically transferred to a position infinitely distant from the observer. Parallax between the reticle and the target is thereby eliminated. Since there are only two optical elements, a reticle and an eyelens, the entire structure can be housed in a compact tube. Generally, the pattern of this reticle is a transparent or illuminated cross on an opaque or dark background. When employed as the sighting device for a weapon, the mount of the collimator is provided with leveling mechanisms and scales which permit the weapon to be placed at a prescribed elevation with relation to the line of sight established by the collimator. Sighting is accomplished by looking into the collimator and at the target simultaneously or successively to superimpose the cross upon the target.

## CHAPTER 5 — REPRESENTATIVE FIRE CONTROL INSTRUMENTS

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### Section I

### TELESCOPIES

#### 86. GENERAL.

a. *Telescope* is the standard nomenclature designation for instruments of a number of different types. Some of the representative types of telescopes illustrated and described in this section are used for observation; others are employed to aim weapons. Of these, the Telescope M6, Telescope M1, and Telescope M70 are of the *straight tube* type; the Observation Telescope M48 and Telescope M31 are of the *prism-offset* type; and the Telescope M60 is of the *periscopic* type.

#### 87. TELESCOPE M6 (ANTITANK).

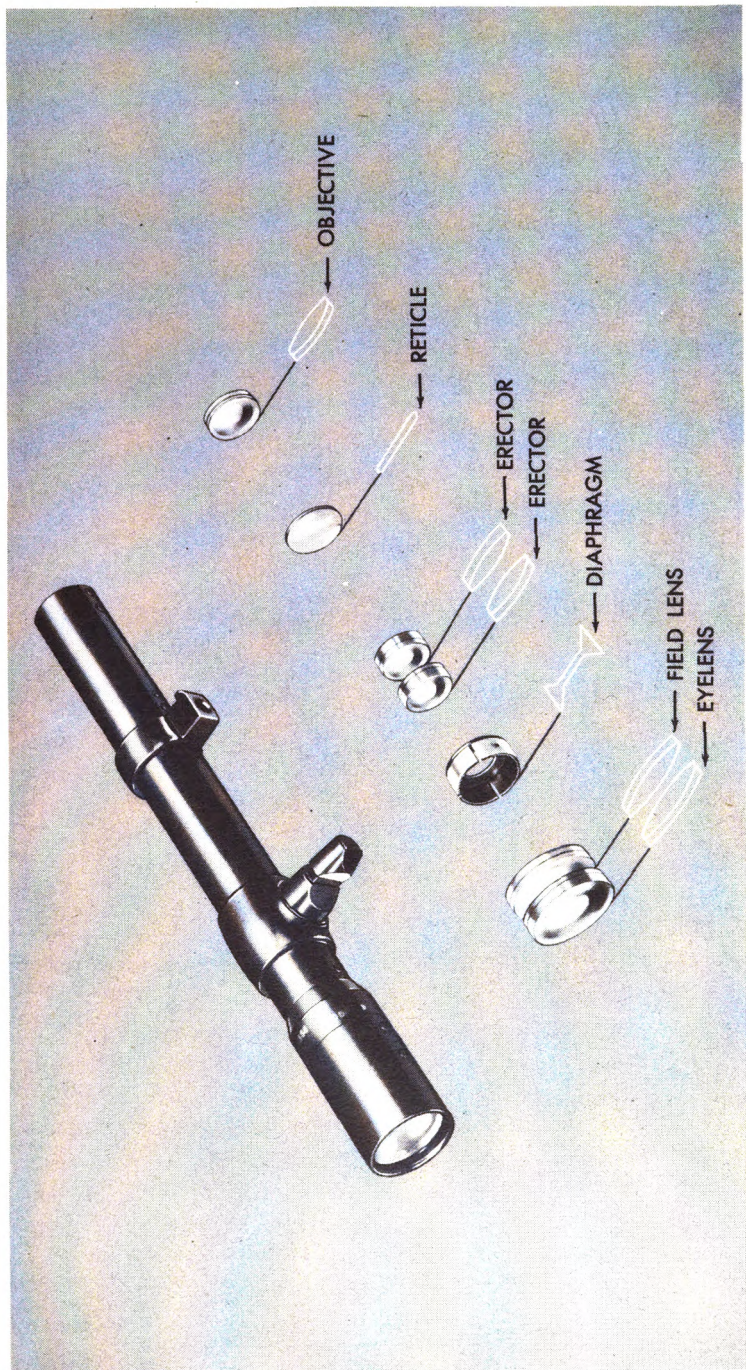
a. The Telescope M6 (fig. 114) is a straight tube telescope with no magnification. With the Telescope Mount M19, it comprises the on-carriage sighting equipment for an antitank gun. This instrument has a lens erecting system and a symmetrical eyepiece. This eyepiece provides a large exit pupil (0.6 in.) and large eye relief (over 4 in.). The large eye relief is provided to avoid contact between the eye of the gunner and the eyepiece when the gun recoils. The field of view is 11 degrees.

b. The telescope reticle (fig. 101g) is graduated for various leads and ranges. To aim the gun, the elevating and traversing mechanisms on the weapon are operated and the target is viewed through the reticle until the dot on the reticle which indicates the proper lead and range is imposed on the target. The reticle is illuminated through a window by an electric lamp, retained by and a part of the mount.

#### 88. OBSERVATION TELESCOPE M48 (OBSERVATION POSTS).

a. The chief purpose of the Observation Telescope M48 (fig. 115) is to assist in the observing of artillery fire. The instrument has a large achromatic objective and an orthoscopic eyepiece. The image is erected by a Porro prism system which gives the instrument its characteristic "offset." There are diaphragms between the objective and the erecting system and between the erecting system and the eyepiece. There is no reticle.

b. This instrument is a 19.6-power telescope having a field of view of 2 degrees 8 minutes and an exit pupil of 0.1-inch diameter. To provide the steadiness required in the use of a high-powered instrument, the telescope is strapped into a cradle mounted on a



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Figure 114 — Telescope M6 — Assembled View, Optical Elements, and Optical Diagram

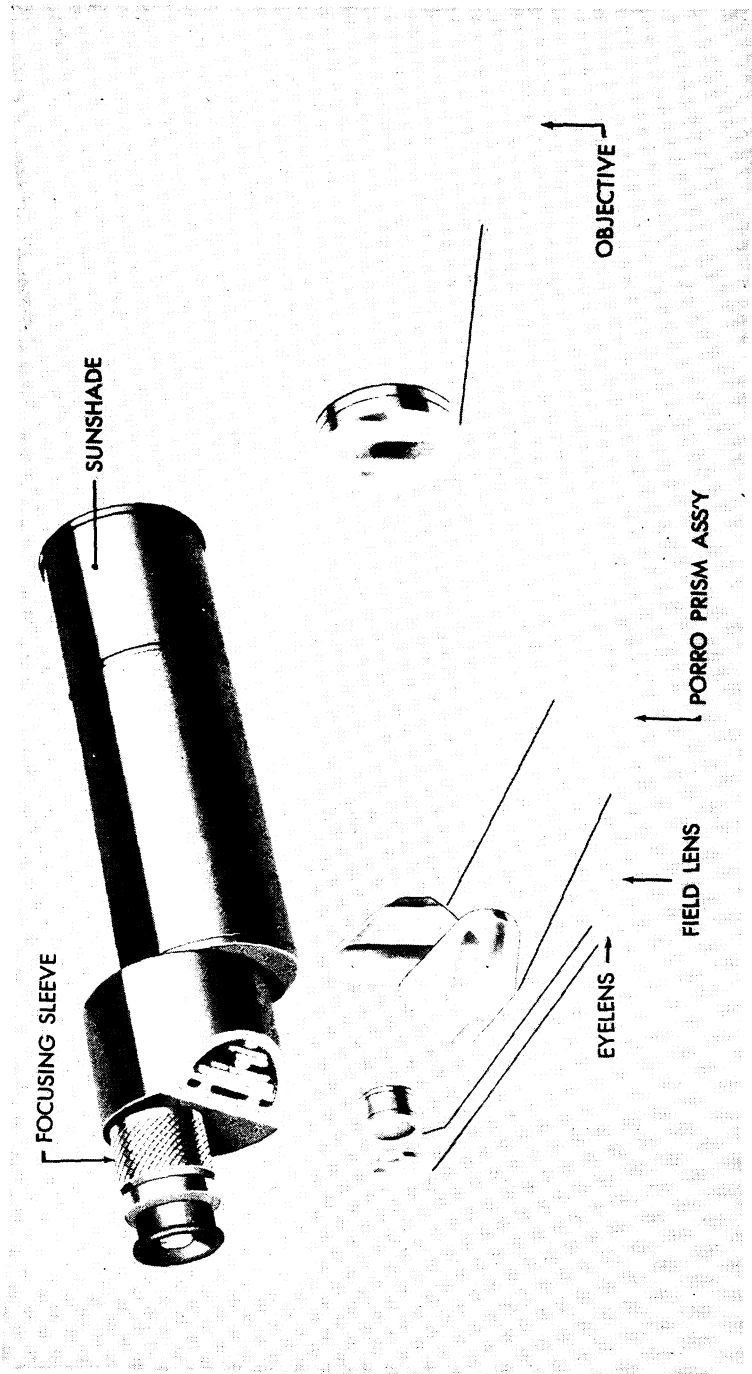
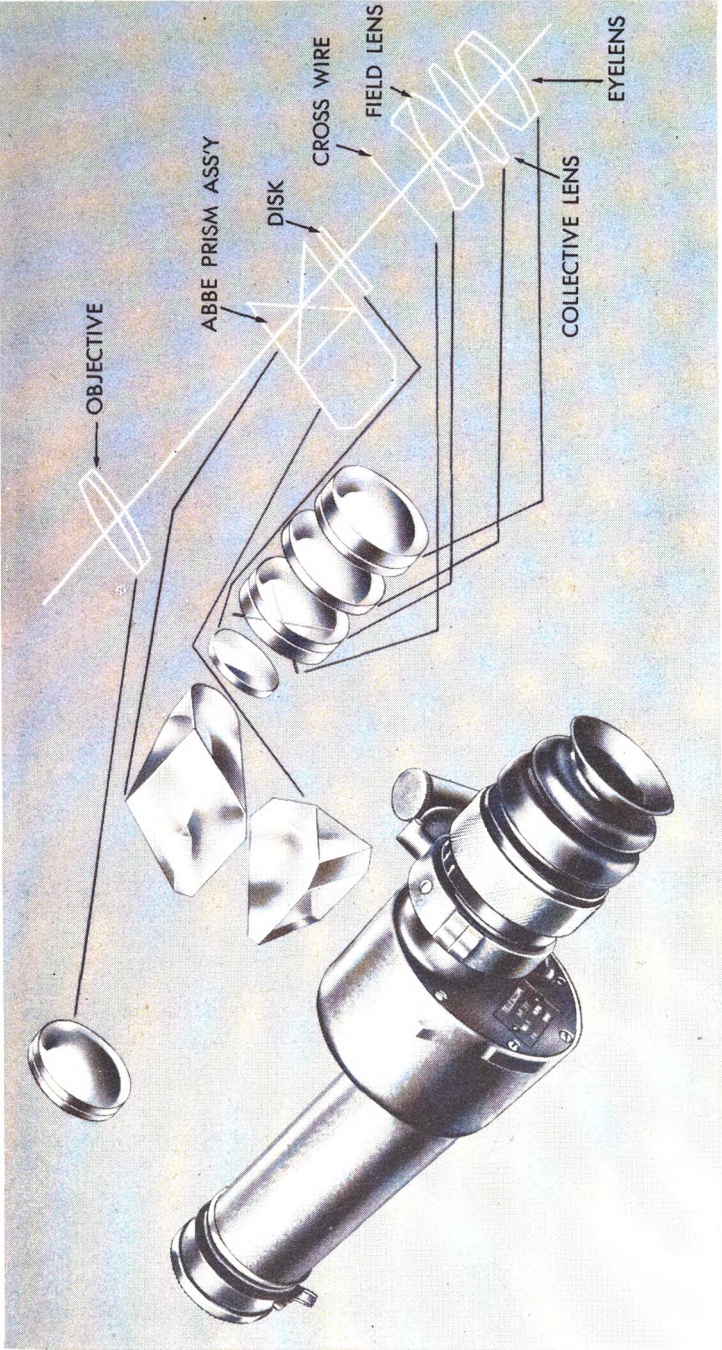


Figure 115 – Observation Telescope M48 – Assembled View, Optical Elements, and Optical Diagram

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Figure 116 — Telescope M31 — Assembled View, Optical Elements, and Optical Diagram

*Representative Fire Control Instruments*

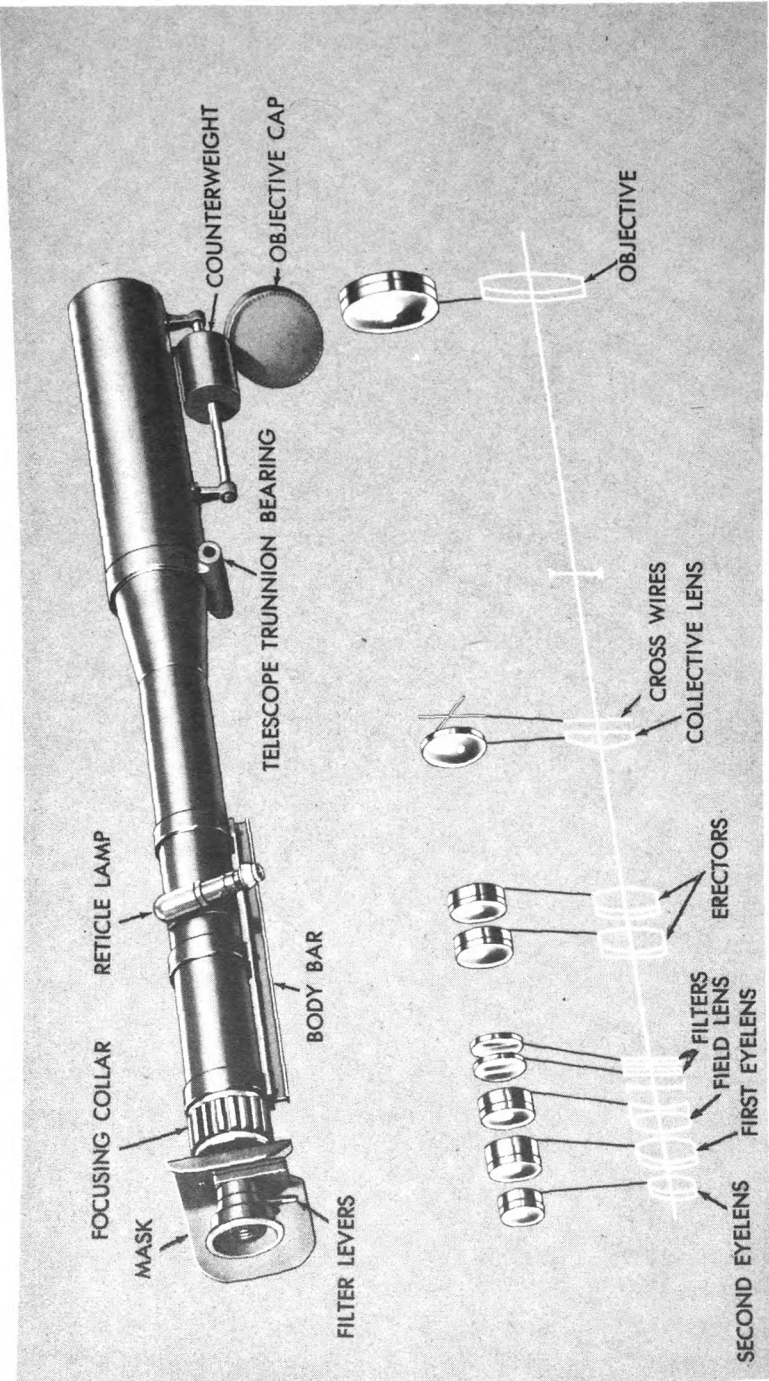


**Figure 117 — Telescope M1 — Assembled View, Optical Elements, and Optical Diagram**

*Representative Fire Control Instruments*

tripod. The objective end of the telescope has a sliding sunshade which may be extended approximately 2 inches, as the need requires. An objective cover and eyepiece cap are furnished which are screwed in place to protect the lenses when the telescope is not in use.

c. The instrument is focused by pushing or pulling the eyepiece in or out until the approximate focus is reached, and then turning the knurled focusing sleeve to obtain exact focus. This arrangement is made possible by a spring-loaded ball which either rides over the threads of the focusing nut when the eyepiece is pushed or pulled, or engages the threads when the eyepiece is turned.

**89. TELESCOPE M31 (SEACOAST ARTILLERY).**

a. The Telescope M31 (fig. 116) is a prism-offset type instrument with 8-power magnification and a field of view of 8 degrees 45 minutes. It is clamped in the cradle of Telescope Mount M35, which is mounted on barbette carriages of seacoast guns and forms the sighting equipment for aiming the weapons in azimuth and for making lateral adjustment of fire.

b. The eyepiece consists of a compound eyelens, a double convex collective lens, and a compound field lens. The erecting system is an Abbe prism assembly (par. 69 c). A cross wire reticle is located between the eyepiece and the erecting system. It is provided with two windows for illumination. The objective is achromatic.

c. The diopter scale is calibrated from plus 3 to minus 3 diopters, and may be prefocused if the eye correction of the observer is known. Amber, neutral, and clear filters can be introduced by turning a filter selector knob. The eyepiece is fitted with a rubber eyeshield. An objective cap covers and protects the objective when the telescope is not in use.

**90. TELESCOPE M1 (DEPRESSION POSITION FINDER M1).**

a. The Telescope M1 (fig. 117) is the optical portion of the instrument known as the Depression Position Finder M1. This instrument is used for measuring from heights above sea level, the true horizontal range of an object on the surface of the sea, and also the azimuth of the object from the azimuth reference mark.

b. The Depression Position Finder M1 consists essentially of the Telescope M1, a mount, and a pedestal. The mount carries the telescope and contains mechanisms for leveling and directing it. When the telescope is directed on the water line of a target, the depression angle is measured mechanically, and the corresponding range, corrected for the curvature of the earth and normal atmospheric refraction, is read directly on a range scale graduated in yards. Internal correction adjustments compensate for tidal variations, abnormal atmospheric refraction, and for heights of instrument other than those for which the range scale is calibrated. Azimuths are read directly from an azimuth scale and micrometer. The instrument is built in

*Representative Fire Control Instruments*

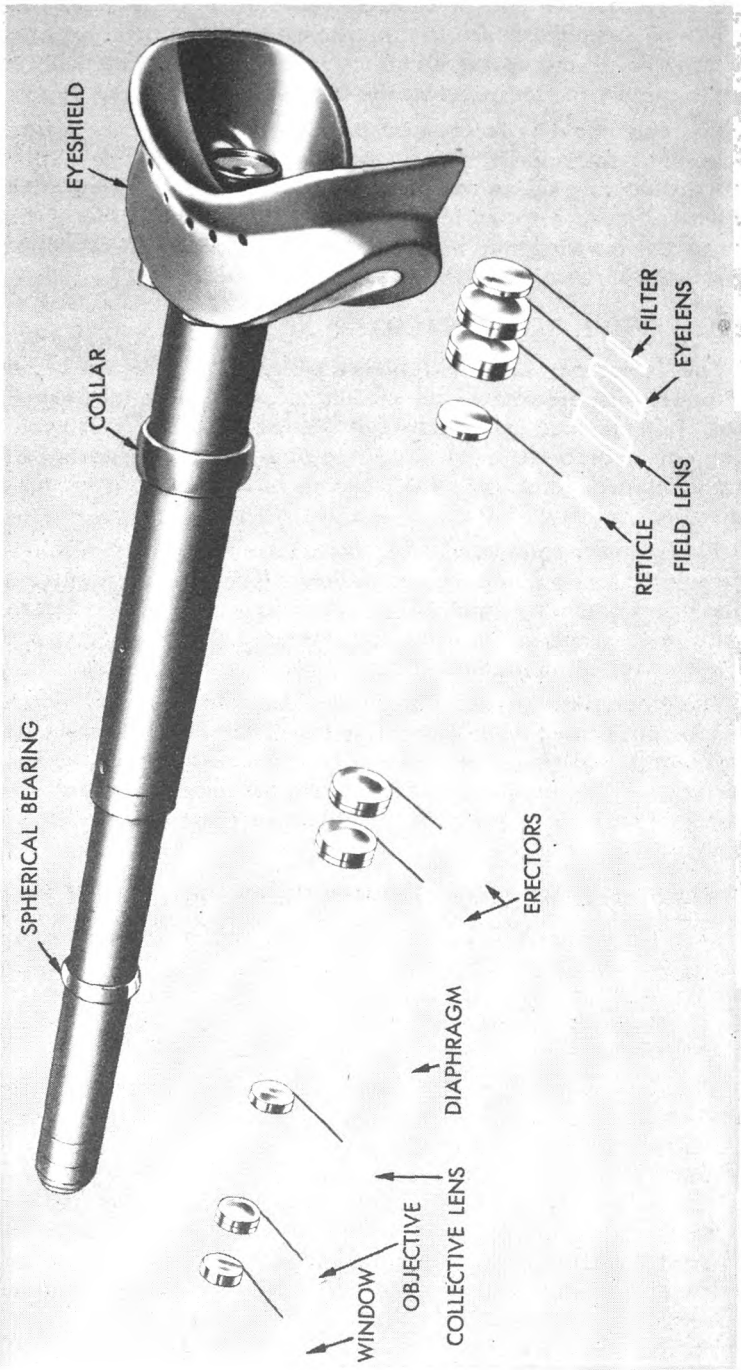


**Figure 118 — Telescope M70 — Assembled View, Optical Elements, and Optical Diagram** RA PD 30160



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*Representative Fire Control Instruments*

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several classes for use at different heights of emplacement above sea level.

c. The Telescope M1 is a straight tube type instrument with variable magnification from 10 to 30 power. The field of view is 6 degrees 9 minutes for 10 power, and 2 degrees 3 minutes for 30 power. The optical system includes an achromatic objective, collective lens, lens erecting system, a blue and amber ray filter assembly, two diaphragms, and an eyepiece assembly of two eyelenses and a field lens. The reticle assembly consists of a reticle frame carrying horizontal and vertical cross wires which intersect in the center of the field of view.

d. The magnification is changed by rotating the focusing collar which varies the distances between the two erectors, between the forward erector and the collective lens, and between the rear erector and the eyepiece diaphragm. Graduations on the focusing collar indicate the magnification for which the telescope is set. As the total rotation of the collar is approximately one and one-quarter turns, the graduations are engraved in part on the rearward rim of the collar and completed on the forward rim.

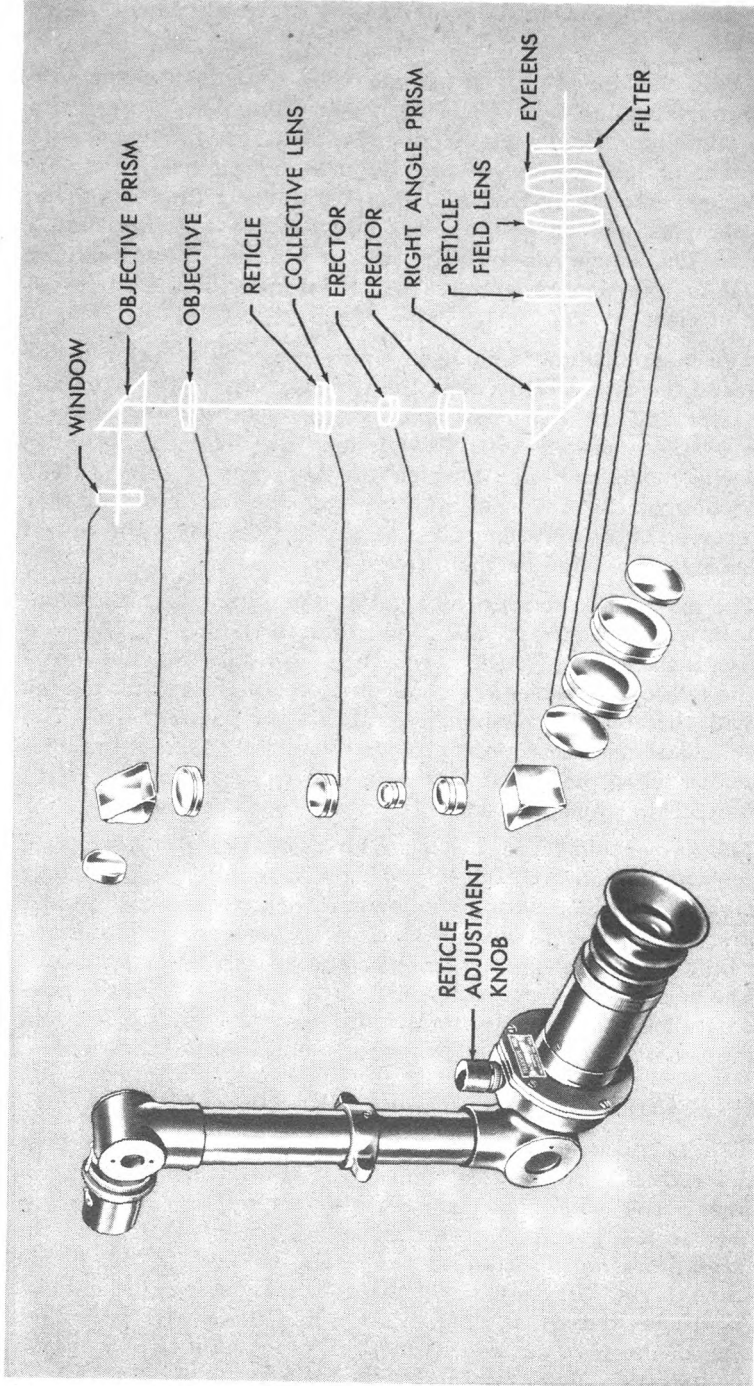
e. The eyepiece is focused by rotating the eyeshield. The diopter scale is graduated from plus 5 to minus 5 diopters. The zero graduation is the setting for the normal eye. A mask on the eyepiece end of the telescope enables the observer to relax the eye that is not being used, thereby minimizing the strain on the focused eye. The objective end of the telescope is provided with a sunshade to protect the objective when the instrument is in use, and a leather objective cap to protect the objective when the instrument is not in use.

f. The amber filter and the blue filter, controlled by separate levers, may be brought into the line of sight as required. The reticle cross wires are provided with a window for daylight illumination and an electric lamp for night illumination. The telescope is positioned in the mount by two telescope trunnions and an accurately machined bar on the under side of the body tube. The optical axis of the telescope is parallel to the lower surface of the bar. An adjustable counterweight assembly is provided for proper balance of the telescope.

## **91. TELESCOPE M70 SERIES (TANKS).**

a. The Telescope M70 (fig. 118) is used in tanks and combat vehicles for direct fire sighting under conditions when a comparatively high power, wide angle telescope is necessary. The telescope is attached to the gun mount and moves with it, so that when the reticle cross lines are directed on the target, the gun is also aimed at the same target. Instruments of this type supplement the indirect vision periscope telescopes (par. 103) when these also are used. Telescopes of the M70 series are identical in appearance and optical characteristics; they differ only in reticle patterns.

Representative Fire Control Instruments



RA PD 30161

Figure 119 — Telescope M60 — Assembled View, Optical Elements, and Optical Diagram

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*Representative Fire Control Instruments*

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b. The Telescope M70 is of the straight tube type with a lens erecting system. The objective end is designed to provide a very small frontal target and requires a very small hole in the armor plate. The achromatic objective is, therefore, smaller in comparison with the size of the eyepiece lenses than that of many other telescopes. The objective is protected by a window. A collective lens aids in securing brightness of image. Magnification of 3 power and a relatively large field of view of 12 degrees 19 minutes keep movement in the field of view to a minimum, yet permit the reticle to be easily seen. The reticle is located between the erecting system and the eyepiece, and instruments with different reticle patterns are furnished for use with different weapons. Reticle lighting is provided.

c. The eyelens and field lens of the eyepiece are compound elements. Removable amber, neutral, or red filters may be assembled to the eyepiece as required. A removable rubber eyeshield fits over the eyepiece end of the telescope to exclude light which might otherwise interfere with normal observation through the instrument. This eyeshield masks the eye not in use. The outside of the telescope is provided with a spherical bearing and collar for use in clamping and accurately positioning the telescope in its holder.

## **92. TELESCOPE M60 (ANTIAIRCRAFT ARTILLERY).**

a. The Telescope M60 (fig. 119) is of the periscopic type, with the line of sighting 12 inches above the observer's line of vision. This is a 3-power instrument with a field view of 13 degrees 25 minutes. The line of sight is bent through two right angles by 90-degree prisms. The upper or objective prism is protected by a window. The achromatic objective is located below the objective prism in the upright tube of the telescope. This tube also carries the lens erecting system and a collective lens. The eyepiece is of the symmetrical type. Removable amber, neutral, and red filters may be applied to the eyepiece as required. A monocular eyeguard is fitted to the eyepiece end of the instrument.

b. The optical system includes two reticles, the patterns of which are seen superimposed upon each other on the target. One of these reticles, carrying a range scale, is located between the eyepiece and the lower prism. It is movable vertically by a knob, thus providing an adjustable range scale. The other reticle, carrying azimuth scale graduations for the establishment of leads, is cemented to the collective lens.

c. Two of these instruments are used as the azimuth and elevation telescopes of the Sighting System M7. This system is used by antiaircraft artillery as antimechanized sighting equipment. The elevation and azimuth operators point the gun for range and direction by rotating the gun tracking handwheels to bring the target on the proper range or deflection graduation on the reticle patterns.

## Section II

### ELBOW TELESCOPES

#### 93. GENERAL.

a. The elbow telescope is used wherever it is necessary to direct the line of sight through a 90-degree angle. This is desirable where the range of the angle of elevation of the instrument is considerable. Telescopes of this type also are used to permit observers to assume the most convenient positions for the operation of their instruments. Such telescopes are employed in the pointing of field artillery, in antiaircraft observation and fire, on plotting boards, and for other purposes.

b. The more conventional types of elbow telescopes employ a 90-degree roof angle or Amici prism to erect the image and bend the line of sight through the right angle. Other elbow telescopes employ a penta prism and a lens erecting system to serve these purposes. There are elbow telescopes of a number of designs, differing in components of the optical system, method of mounting, and other details, depending upon the purpose of the instrument. The specific instruments described herein are representative of the type.

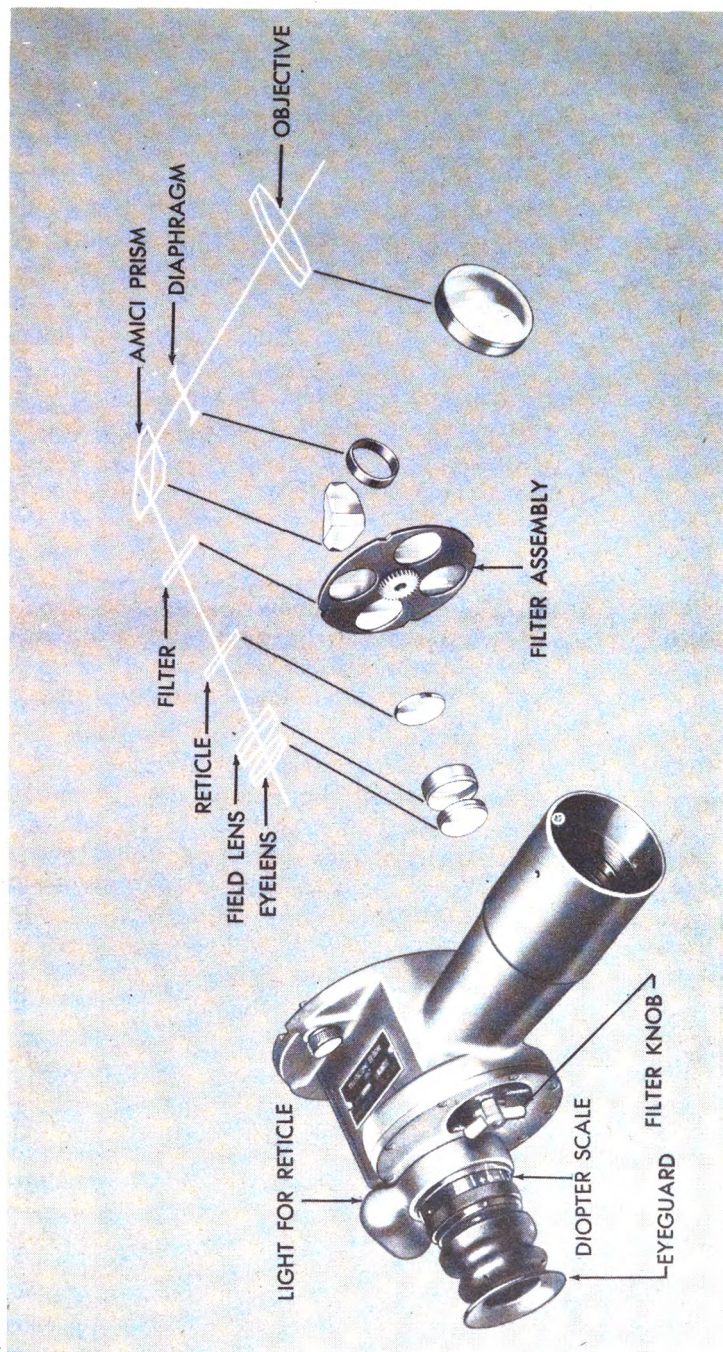
#### 94. ELBOW TELESCOPE M17 (ANTIAIRCRAFT DIRECTORS).

a. Two elbow telescopes are used as the optical components of an antiaircraft director for tracking or maintaining lines of sight in elevation and in azimuth on an aircraft in flight.

b. The Elbow Telescope M17 (fig. 120) is an 8-power instrument with a field of view of 6 degrees. The image is erected and the line of sight is bent 90 degrees by an Amici prism. The objective, eyelens, and field lens are of compound type. A cross line reticle is located between the eyepiece and the filter assembly. By turning a filter knob on the body of the instrument, red, amber, neutral, or clear filters can be rotated into the line of sight as required. The reticle is illuminated by an electric lamp at night. The eyepiece is adjustable from minus 4 to plus 2 diopters to adapt the focus to the eyes of the observer; a diopter scale permits prefocusing.

#### 95. ELBOW TELESCOPES M24 AND M26 (ANTIAIRCRAFT ARTILLERY).

a. Elbow Telescopes M24 and M26 (fig. 121) are identical, except for their reticle patterns. They are 3-power instruments with a field of view of 13 degrees 20 minutes. The Elbow Telescope M24 for aiming in azimuth and the Elbow Telescope M26 for aiming in elevation are used simultaneously on the same antiaircraft gun as auxiliary direct fire sighting equipment. Similar instruments are used on field artillery.

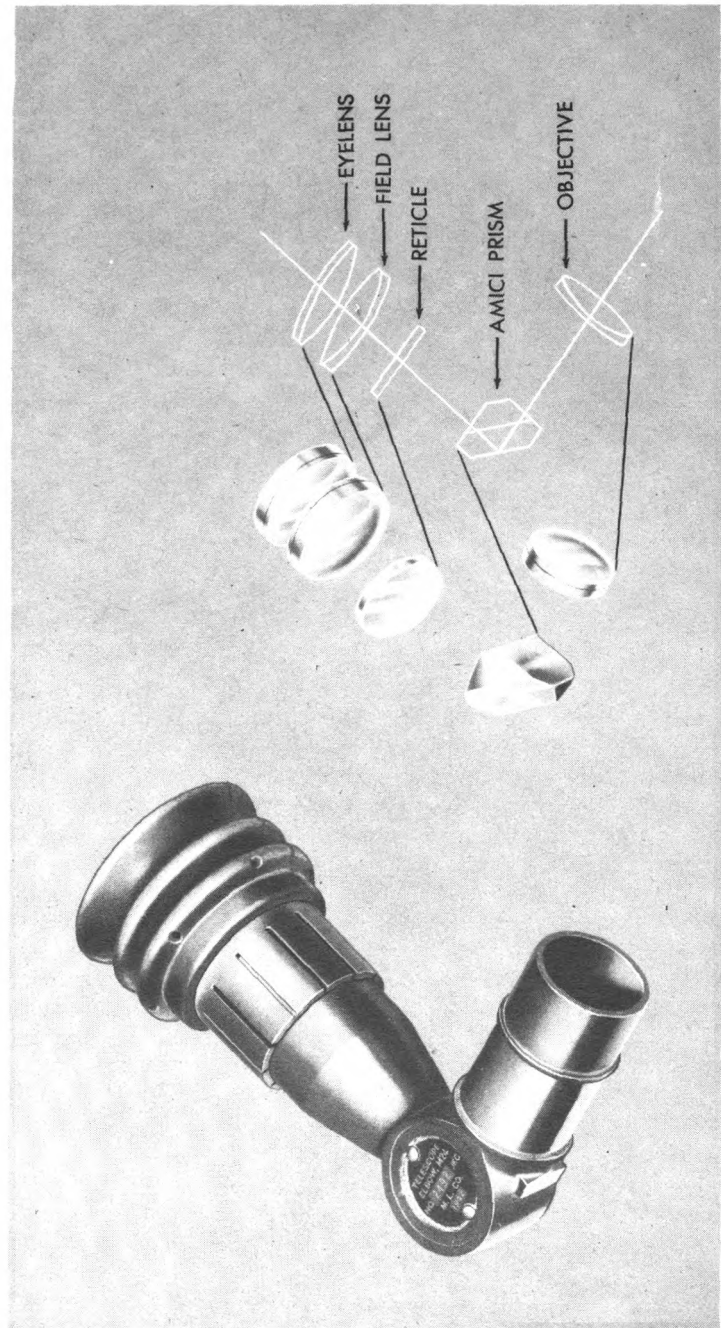


RA PD 30162

Figure 120 — Elbow Telescope M17 — Assembled View, Optical Elements, and Optical Diagram



*Representative Fire Control Instruments*



**RA PD 30163**  
**Figure 121 — Elbow Telescopes M24 and M26 — Assembled View, Optical Elements, and Optical Diagram**

*Representative Fire Control Instruments*

b. The objective, eyelens, and field lens are of compound type, the eyepiece being of symmetrical design without provision for focusing. An Amici prism erects the image and bends the line of sight through 90 degrees. The reticle is located between the eyepiece and the prism. The reticle of the Elbow Telescope M24 is graduated for azimuth deflections and leads; that of the Elbow Telescope M26 carries a range scale for setting in elevations.

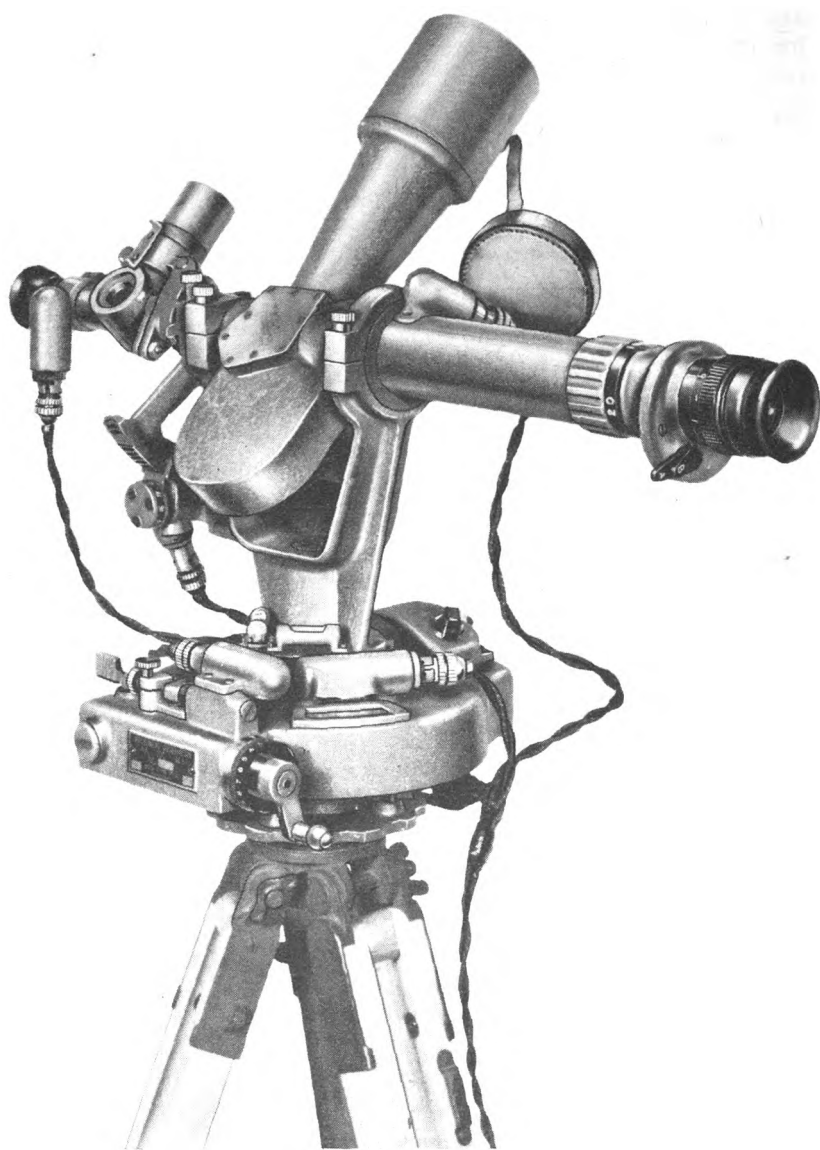
**96. AA BC OBSERVATION INSTRUMENT M1 (ANTIAIRCRAFT ARTILLERY).**

a. The Antiaircraft Battery Commander's Observation Instrument M1 (fig. 122) is used for spotting in observation and tracking rapidly moving aerial or ground targets.

b. The optical portion of the instrument consists of an observer's telescope, used by the observer to locate and follow the target, and another elbow telescope, which is trained on the target by the observer's telescope and which is available to the battery commander at all times for observing and spotting. The telescope for the observer is the Elbow Telescope M2; the telescope for the battery commander is either the Elbow Telescope M35 or the Telescope (elbow) M3. The latter telescopes are similar in external construction and operation but differ in the construction of the variable power mechanism. The observer's and the battery commander's telescopes are connected by an adapter which provides means for alining the lines of sight of the two instruments.

c. **Elbow Telescope M2.** This is an 8-power instrument with a field of view of 8 degrees 45 minutes (fig. 123). The objective is achromatic. An Amici prism erects the image and bends the line of sight through 90 degrees. The cross line reticle is lighted by an electric lamp. The three-element eyepiece consists of an eyelens, collective lens, and field lens. The eyepiece is fixed, no provision being made for adjustment to accommodate the observer's eyes for various errors. Separate blue and amber filters may be affixed to the eyepiece as required. An open sight enables the observer to pick the target up rapidly.

d. **Telescope M3.** The Telescope M3 (fig. 123) is adjustable in magnification, giving 10 power with a field of view of 6 degrees 9 minutes, or 20 power with a field of view of 3 degrees 5 minutes. The eyepiece has two eyelenses and a plano-convex field lens. The objective is achromatic. A penta prism is used to direct the line of sight through the 90-degree angle. A lens erecting system erects the image. When the magnification is changed from low to high power or vice versa, the erectors, while remaining close together, are moved to different positions relative to one another and to other elements of the system. Magnification is changed by rotation of the knurled focusing sleeve. A reticle cemented to a reticle lens is located between the penta prism and the erecting system. The reticle is gradu-



RA PD 30164

**Figure 122 — AA BC Observation Instrument M1**



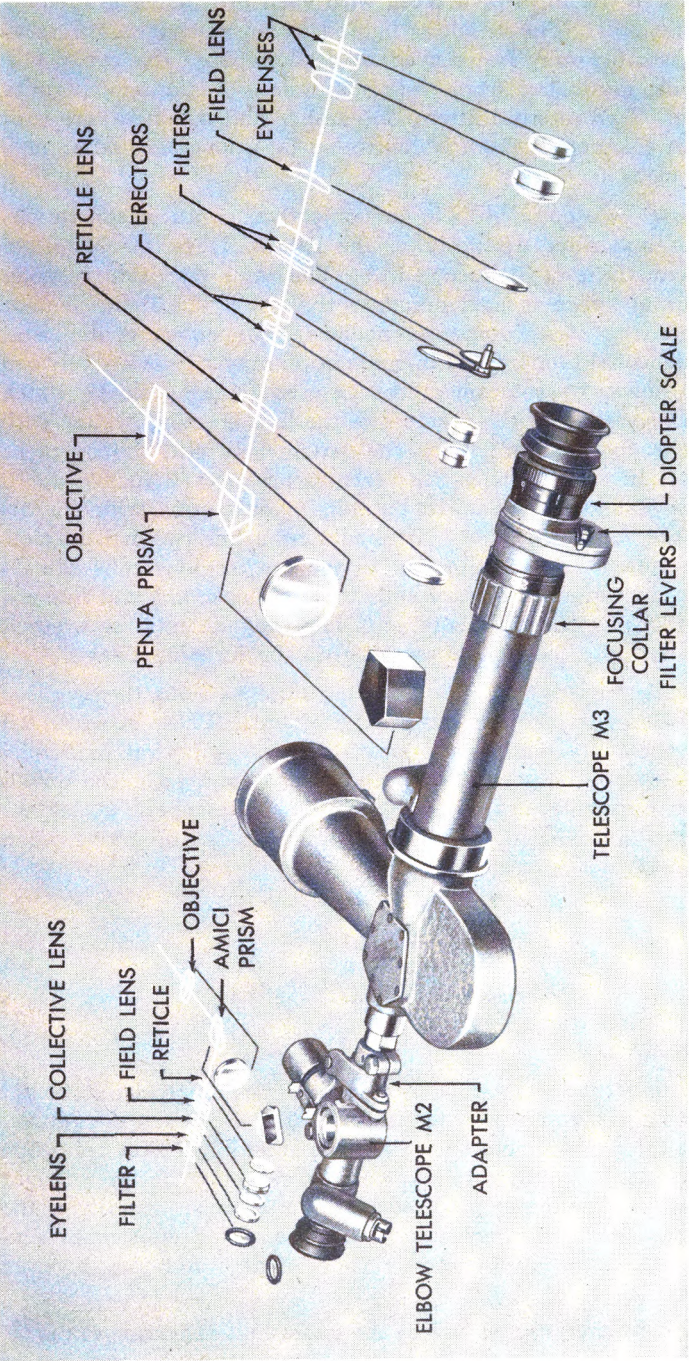


Figure 123 — AA BC Observation Instrument M1 — Elbow Telescope M2 and Telescope M3 — Assembled View, Optical Elements, and Optical Diagrams

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*Representative Fire Control Instruments*

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ated in mils in the form of a cross with each arm being graduated from 5 to 50 mils. The reticle is lighted by an electric lamp. The eyepiece assembly may be focused to accommodate the eye. The diopter scale, graduated from plus 3 to minus 3 diopters, permits prefocusing. Two internal filters, one amber and one blue, are provided in the telescope. Each is controlled by a lever extending outside the housing.

e. **Elbow Telescope M35.** The objective, penta prism, reticle, reticle lens, and filter assembly of the Elbow Telescope M35 are identical with those of Telescope M3. The same provision is made to focus the eyepiece to accommodate the eye. The three-element eyepiece consists of a compound eyelens, equi-convex center lens, and compound field lens. The magnification may be varied between 10 and 20 power by rotation of the knurled focusing sleeve which changes the positions of the erectors of the lens erecting system with relation to each other and with the reticle lens and the eyepiece diaphragm. In all positions, the erectors are over 2 inches apart. The focusing sleeve mechanism contains a cam tube which is attached to the focusing sleeve. The cam tube has two helical slots of different pitch. Shoes attached to the erector lens cells ride in these slots and cause the erector cells to slide backward and forward when the focusing sleeve is rotated. The magnification secured at any setting is indicated by the marking on the focusing sleeve.

f. The telescope body has two bearing surfaces along the eyepiece leg of the telescope for clamping to the mount. These straddle the portion of the body holding the penta prism. A pocket extending from the telescope body is filled with lead to counteract the unbalance of the objective legs of the two elbow telescopes. A leather objective cap attached to the sunshade protects the objective when the telescope is not in use.

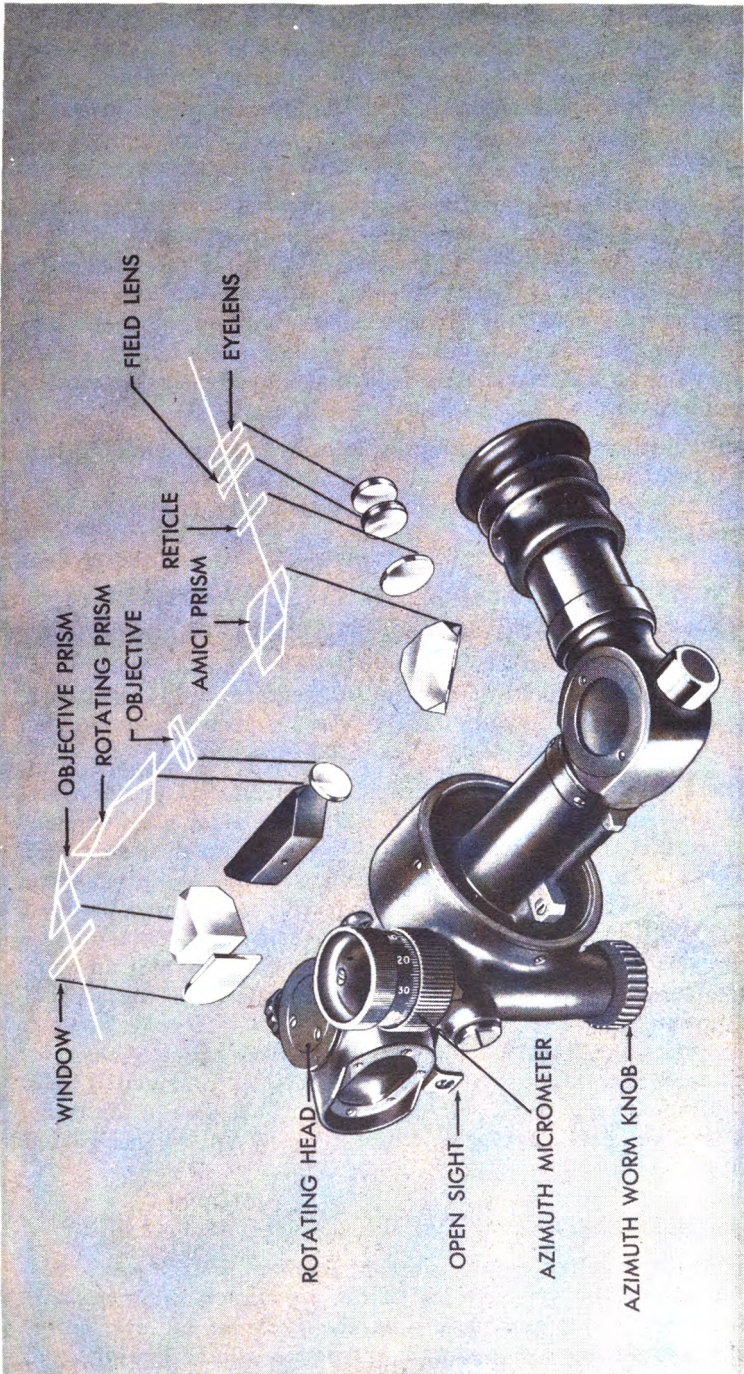
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**Section III****PANORAMIC TELESCOPES****97. GENERAL.**

a. The panoramic telescope is a type of fire control instrument employed to aim a gun or howitzer in azimuth. It is used in conjunction with a telescope mount to which it is assembled. The telescope mount travels in azimuth with the weapon, carrying the line of sight of the telescope. The telescope provides the mechanism for setting the azimuth angle while the mount or other associated equipment supplies the elevation, angle of site (vertical angle), and cross-leveling mechanism.

b. The characteristic feature of the panoramic telescope is that it raises the line of sight and maintains an upright image regardless of





RA PD 30166

Figure 124 — Panoramic Telescope M12 — Assembled View, Optical System, and Optical Diagram

*Representative Fire Control Instruments*

whether the line of sight is directed forward, to the side, or to the rear of the observer. The upper or rotating head of the instrument and the line of sight may be rotated 360 degrees or through any desired angle in the horizontal plane without requiring the observer to change his position. The mount provides for the raising or lowering of the line of sight to any required angle. By the combination of these motions, the line of sight can be directed on any aiming point.

c. The different types and models of panoramic telescopes are of the same basic design. They differ in the components of their optical systems, the angle at which the eyepiece is mounted with relation to the upright body of the instrument, the indexing of the scales, provisions for setting in deflections, method of mounting, reticle patterns, manner of adjustment, lighting, and other details. A number of these differences are determined by the characteristics of the materiel with which the instrument is used.

d. An objective prism, a rotating prism, and an Amici prism (fig. 124) comprise the erecting system of the great majority of panoramic telescopes. An erecting prism assembly (fig. 126) may be used in place of the rotating prism.

### 98. PANORAMIC TELESCOPE M12 (FIELD ARTILLERY).

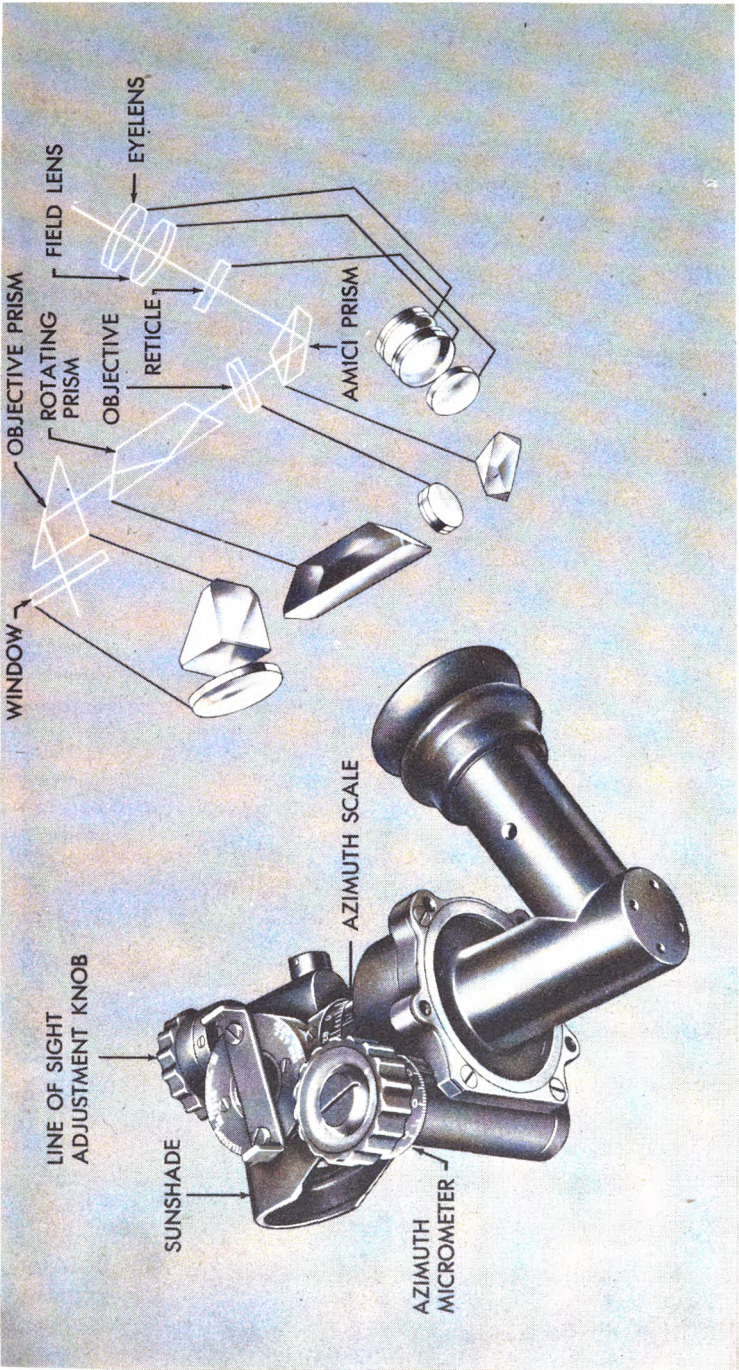
a. The Panoramic Telescope M12 (fig. 124) is one of the most modern adaptations of the conventional design. It has a magnification of 4 power and a field of view of 10 degrees. It is used on a telescope mount primarily to point a gun or howitzer in azimuth for indirect fire and may also be used for direct fire.

b. The erecting system is comprised of an objective prism, rotating prism, and Amici prism (figs. 88 and 99). A plane glass window in the rotating head protects the optical system from dirt, dust, and other foreign matter; it particularly protects the objective prism from scratches and breakage. A compound objective is mounted between the rotating prism and the Amici prism. The eyepiece is of the Kellner type with an achromatized doublet field lens and an equi-convex eyelens. A reticle with appropriate pattern for the type of materiel used is mounted in the focal plane of the objective between the Amici prism and the eyepiece. The model designation of the telescope indicates the reticle pattern. The reticle is illuminated by a lighting system for night use. An open sight on the side of the rotating head enables the observer speedily to pick up the designated target.

### 99. PANORAMIC TELESCOPE M1 (FIELD ARTILLERY).

a. A distinguishing feature of the Panoramic Telescope M1 (fig. 125) is that the eyepiece leg of the instrument slants upward at an angle of 25 degrees, permitting the observer to look downward at this angle and yet maintain a true horizontal line of sight.

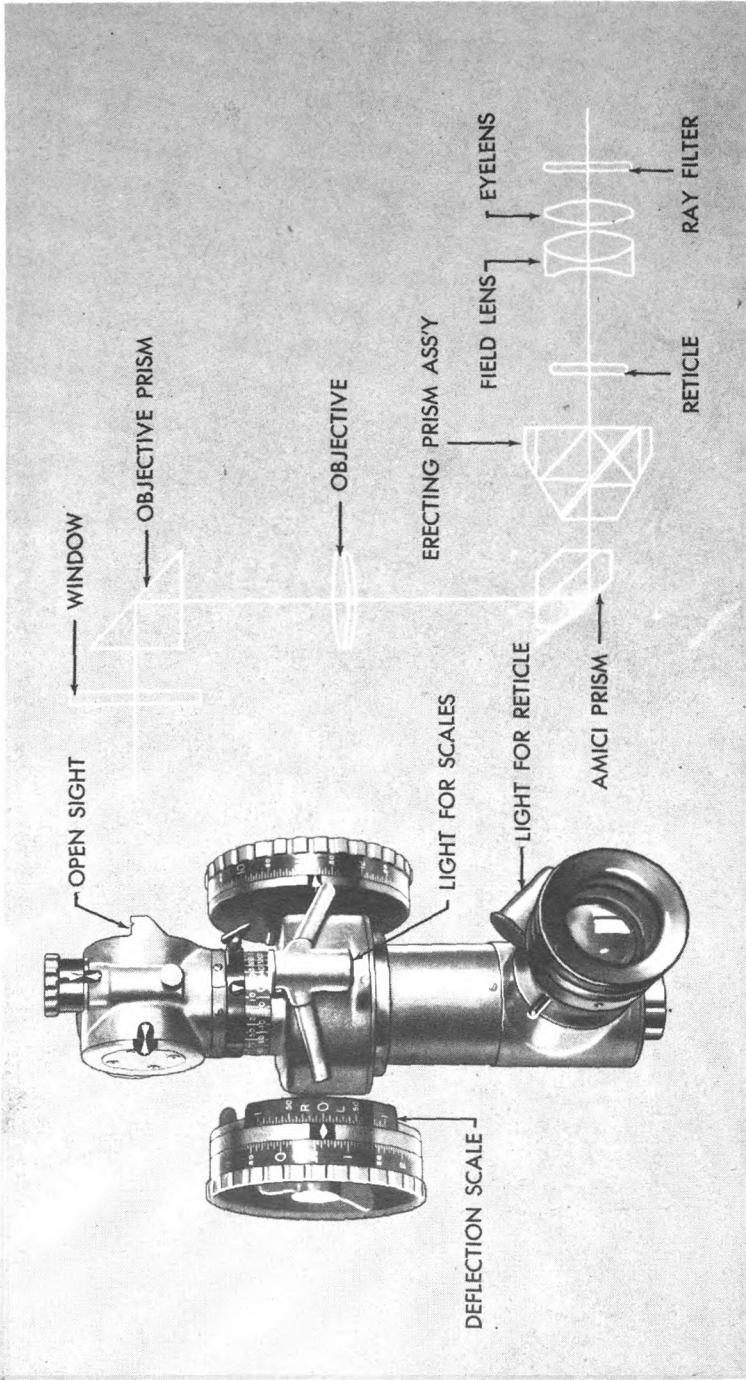




RA PD 30167

Figure 125 — Panoramic Telescope M1 — Assembled View, Optical System, and Optical Diagram

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RA PD 30168

Figure 126 — Panoramic Telescope M8 — Assembled View and Optical Diagram

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*Representative Fire Control Instruments*

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This is an advantage in the aiming of some types of weapons. In other standard types of panoramic telescopes the eyepiece is horizontal. Because of the angle of the eyepiece, a special 115-degree Amici prism is incorporated in the otherwise conventional panoramic telescope erecting system.

b. The instrument has a magnification of 3 power and a field of view of 12 degrees 12 minutes. The objective is located between the rotating Amici prisms. A plane glass window protects the objective prism. The symmetrical type eyepiece has a compound eyelens and field lens. The reticle, of the cross line type, is located between the Amici prism and the eyepiece. It is illuminated by a window and electric lamp.

#### **100. PANORAMIC TELESCOPE M8 (SEACOAST ARTILLERY).**

a. The optical system of the Panoramic Telescope M8 (fig. 126) departs from the conventional type in that while an objective prism and an Amici prism are components of the erecting system, an erecting prism assembly is employed in place of a Dove or rotating prism. The objective prism is located in the rotating head, the Amici prism is mounted in the bottom of the upright body, and the achromatic objective is located between these two elements. The erecting prism assembly is positioned in the eyepiece leg between the Amici prism and the reticle. A plane glass window protects the objective prism.

b. The instrument has a magnification of 6 power, relatively high power being a requirement. The field of view is 6 degrees 40 minutes. The optical elements of the eyepiece are an equi-convex eyelens and a compound field lens. Amber and neutral ray filters are supplied, which may be affixed to the eyepiece when required. The cross line reticle, located between the eyepiece and the erecting prism assembly, is lighted by an electric lamp.

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### **Section IV**

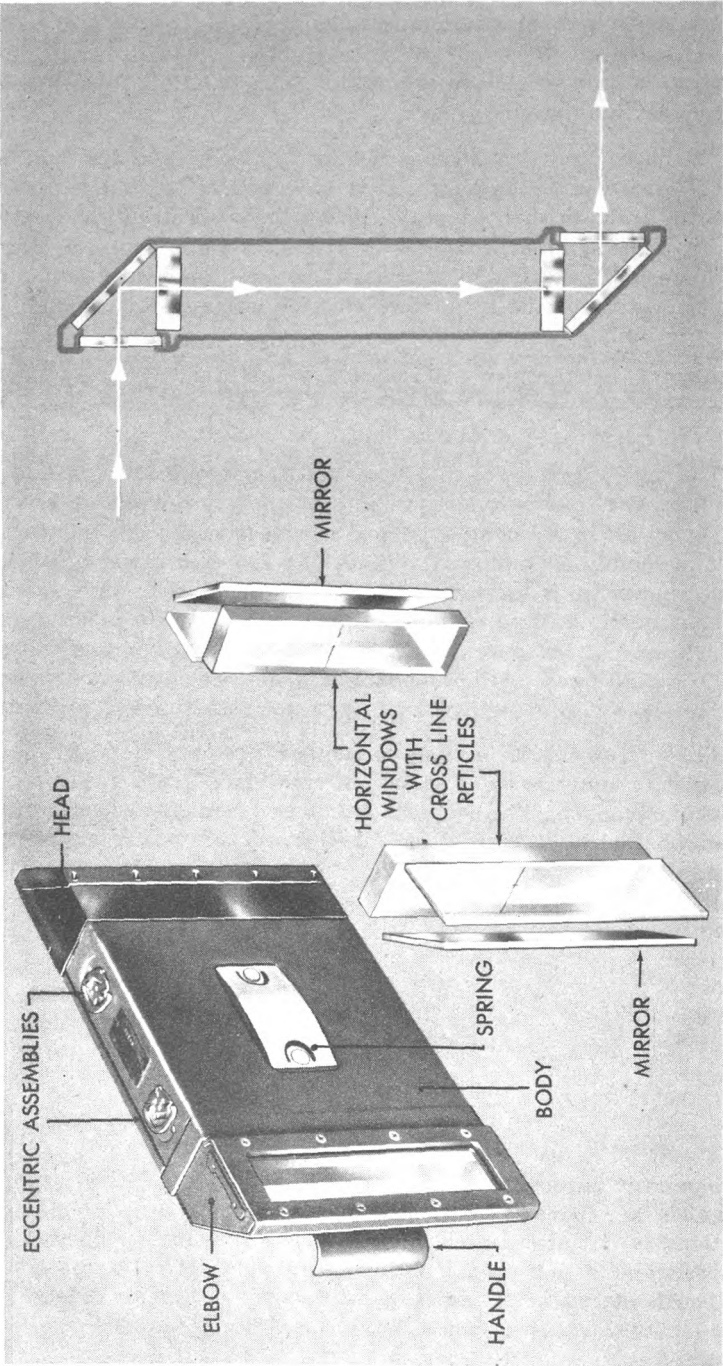
### **PERISCOPES**

#### **101. GENERAL.**

a. The basic purpose of the periscope is to raise the line of vision in order that targets may be seen from entrenchments, or from behind obstructions, or out of enclosed vehicles. The principle of operation of the periscope is that double reflection of light from two parallel mirrors, each placed at a 45-degree angle and with their reflecting surfaces facing each other (fig. 127), forms a normal erect image of the object.



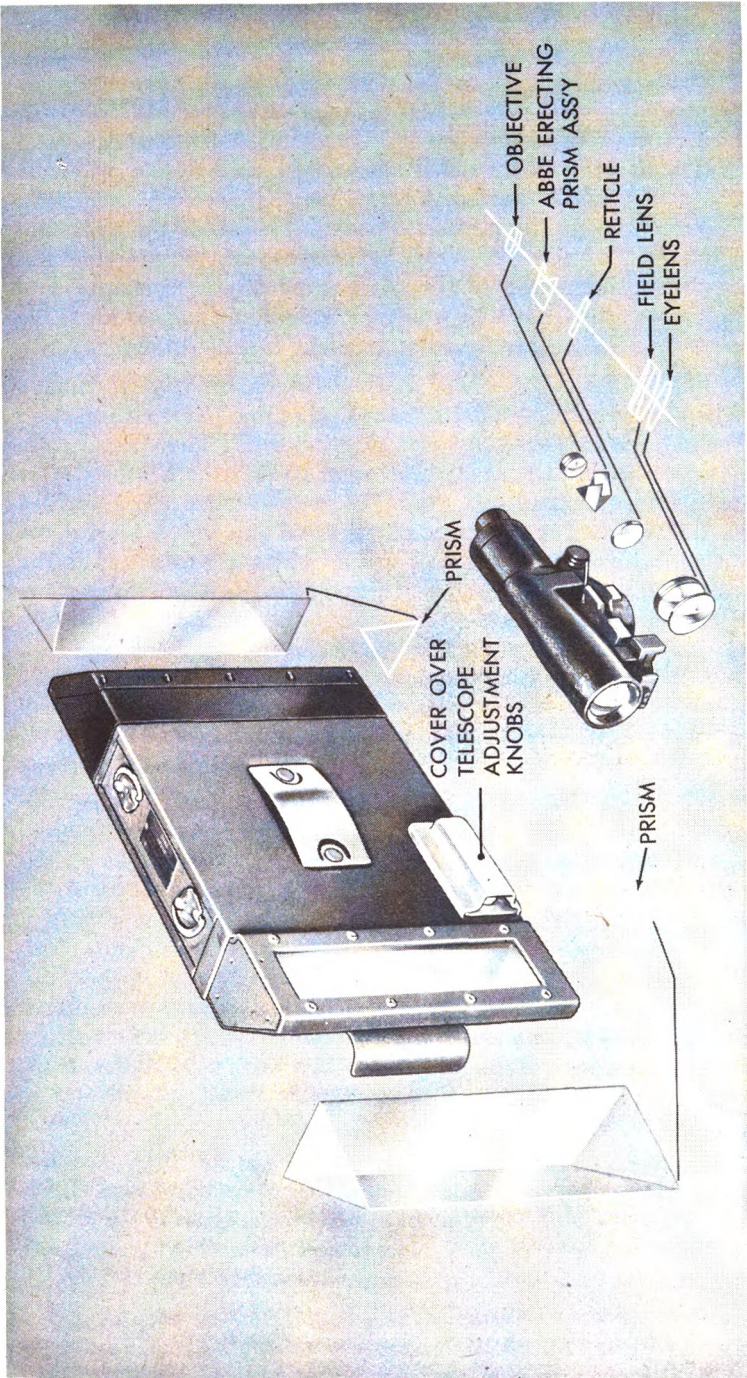
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KA PD 30169

Figure 127 — Periscope M6 — Assembled View, Optical Elements, and Diagram of Principle of Operation





RA PD 102541

Figure 128 — Periscope M4A1 With Telescope M38A2 — Assembled Views, Optical System, and Optical Diagram

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**102. PERISCOPE M6 (TANK OBSERVATION).**

a. The Periscope M6 (fig. 127) is an observation instrument used to view outside objects from the inside of a tank. It is not equipped with a telescope. It has a rectangular body with a removable top or *head* and a removable bottom or *elbow*. The top surface of the head and the bottom surface of the elbow slant at the same 45-degree angle. Clamps attached to the head and elbow engage latches operated by eccentric assemblies in the periscope body. They hold the head and elbow firmly on the body, yet permit ready removal. Plastic material is used in the construction of the head to permit it to shatter into small fragments when struck by a projectile, and not jam or injure the periscope body. Spare heads are furnished for replacement. When the periscope is in place, only the head projects through the tank.

b. The optical system (fig. 127) consists of two plane mirrors, two vertical windows, and two horizontal windows. The mirrors are mounted at 45-degree angles, parallel to and facing each other. One mirror is mounted in the head, the other in the elbow. The vertical windows are mounted in the front of the head and in the rear of the elbow. The horizontal windows, of thicker glass, are mounted in the bottom of the head and in the top of the elbow. Gaskets around the edges of the windows provide a seal against the entrance of dust and moisture. Cross lines are etched on the horizontal windows for rough sighting in observation.

**103. PERISCOPE M4A1 WITH TELESCOPE M38A2 (TANK OBSERVATION AND SIGHTING).**

a. The Periscope M4A1 (fig. 128) is a tank gun sighting and observation instrument. It is fitted with a telescope which is mounted in the right side of the periscope body. The periscope holder in the tank is linked to the gun trunnion so that the line of sighting of the telescope moves with the axis of the gun when the gun is elevated, depressed, or traversed. The Periscope M4A1 differs from the Periscope M6 (par. 102) in that it contains a telescope and is therefore provided with telescope mounting and adjusting mechanisms. Also, the Periscope M4A1 has provision for illuminating the reticle of its telescope, and the optics of the head and elbow each consist of a single solid glass prism instead of the three glass elements (one mirror and two windows) as in the M6.

b. The telescopes fitted into this periscope are for direct fire and observation. There are a number of telescopes of similar design which may be used with this periscope. Each has a reticle pattern matched to the ballistics of a specific gun. The model designation of the telescope indicates the reticle pattern. These instruments are compactly designed to be accommodated in the periscope.

c. The Telescope M38A2 (fig. 128) is typical of the instruments designed for this use. It is of the prism offset type with a magnifica-

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tion of 1.44 power, a field of view of 9 degrees, and considerable eye relief. The magnification is relatively low so that the movement of the tank will keep movement of the field to a minimum, yet provide enough magnification to permit the reticle to be seen readily. The objective is a compound achromatic lens. An Abbe prism erecting system (fig. 98) is used. The Kellner type eyepiece contains an equi-convex eyelens and a compound field lens. The reticle is inverted in order to appear in its normal position after reflection from the lower mirror.

d. Adjustment knobs with graduated scales for lateral deflection and elevation are located on the rear of the body. These permit bore sighting of individual heads with the gun. Adjustment data is recorded, prior to action, on notation labels attached to the rear of spare heads. When replacing a shattered head, this adjustment data is used to make the required adjustment in the field without bore sighting.

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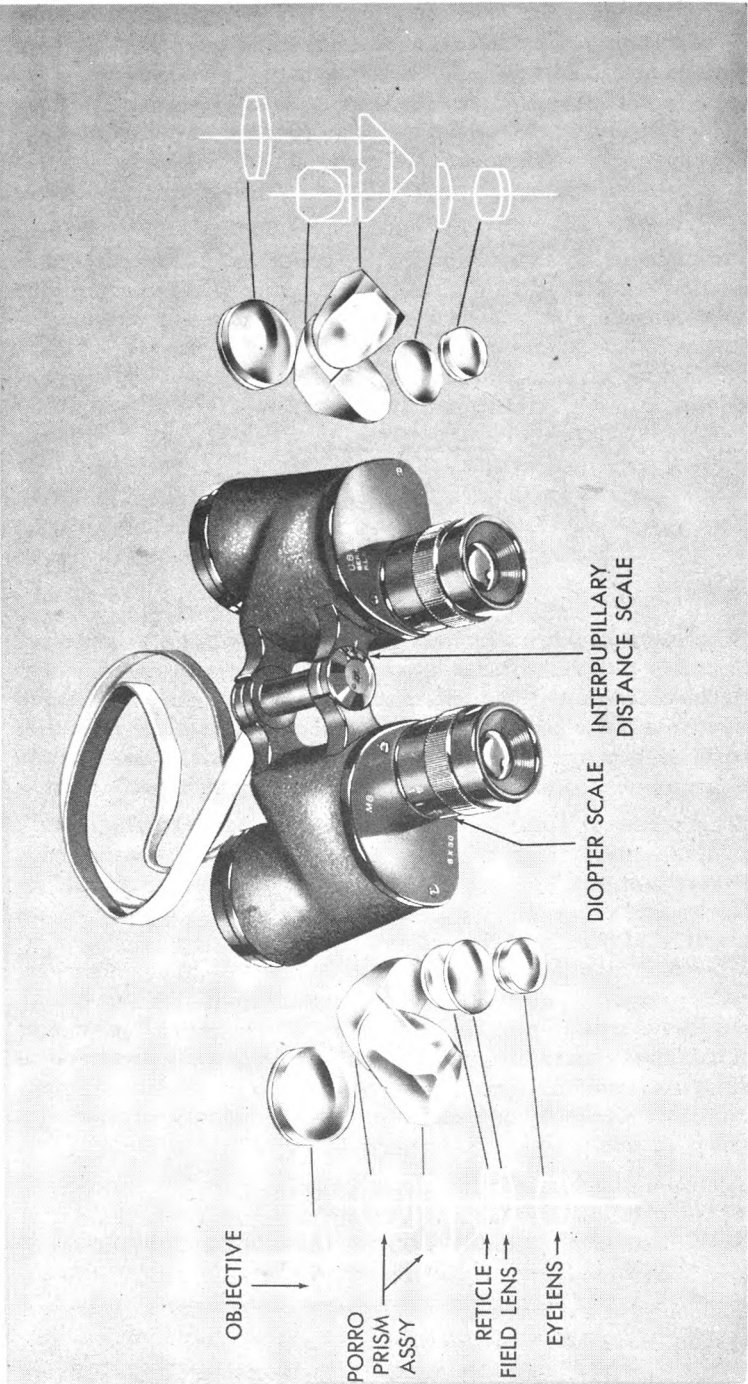
**Section V****BINOCULARS****104. GENERAL.**

a. A military binocular or field glass consists of two prism offset type telescopes pivoted about a hinge which provides adjustment for interpupillary distance. The left telescope of many models contains a reticle with a range scale pattern (fig. 118). An erecting system is required in each of the halves of the instrument; prisms are used to increase stereoscopic vision and to provide a compact instrument.

b. The power of magnification of the binocular, like that of the monocular telescope, depends upon the focal lengths of the objective and eyepiece groups. The true field of view depends upon the design of the lenses and the power. The brightness of image depends upon the size of the objective. The amount of the exit pupil that can be used depends upon the size of the pupil of the eye of the observer, which varies from about 0.1 inch for very brilliant illumination to about 0.3 inch for very faint illumination. The design of an instrument of this type determines its suitability for a specific purpose. A binocular with large objectives and exit pupils is generally better suited for observation at night and other conditions of poor visibility. A binocular of this type is often referred to as a "night glass."

c. Binoculars are usually designated by the power of magnification and the diameter of the objectives. Thus, a 6 by 30 binocular magnifies 6 diameters and has objectives which are 30 millimeters in diameter. This designation is usually stamped on the instrument.

d. Binoculars permit the use of and increase the radius of stereoscopic vision. The observer views the object from the two objec-



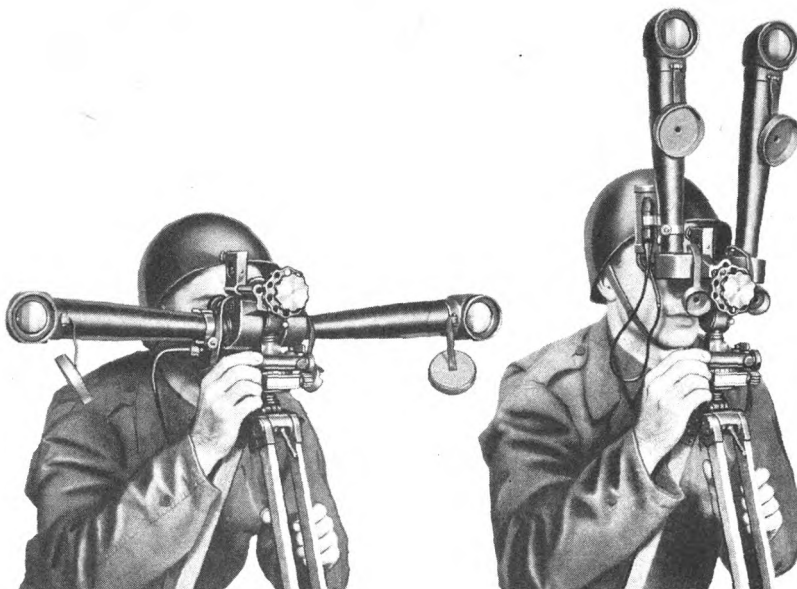
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Figure 129 — Binocular M13A1 — Assembled View, Optical System, and Optical Diagram

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RA PD 30172

**Figure 130 – BC Telescope M1915A1 – In Use**

tives which are more widely separated than his eyes while the magnification provided by the instrument increases his range of vision. For example, if the distance between the lines of sight of his eyes is doubled by the use of prism binoculars, and a 6-power instrument is used, the radius of stereo-vision is increased from a normal of approximately 500 yards to approximately 6,000 yards (500 yards times 2 times 6).

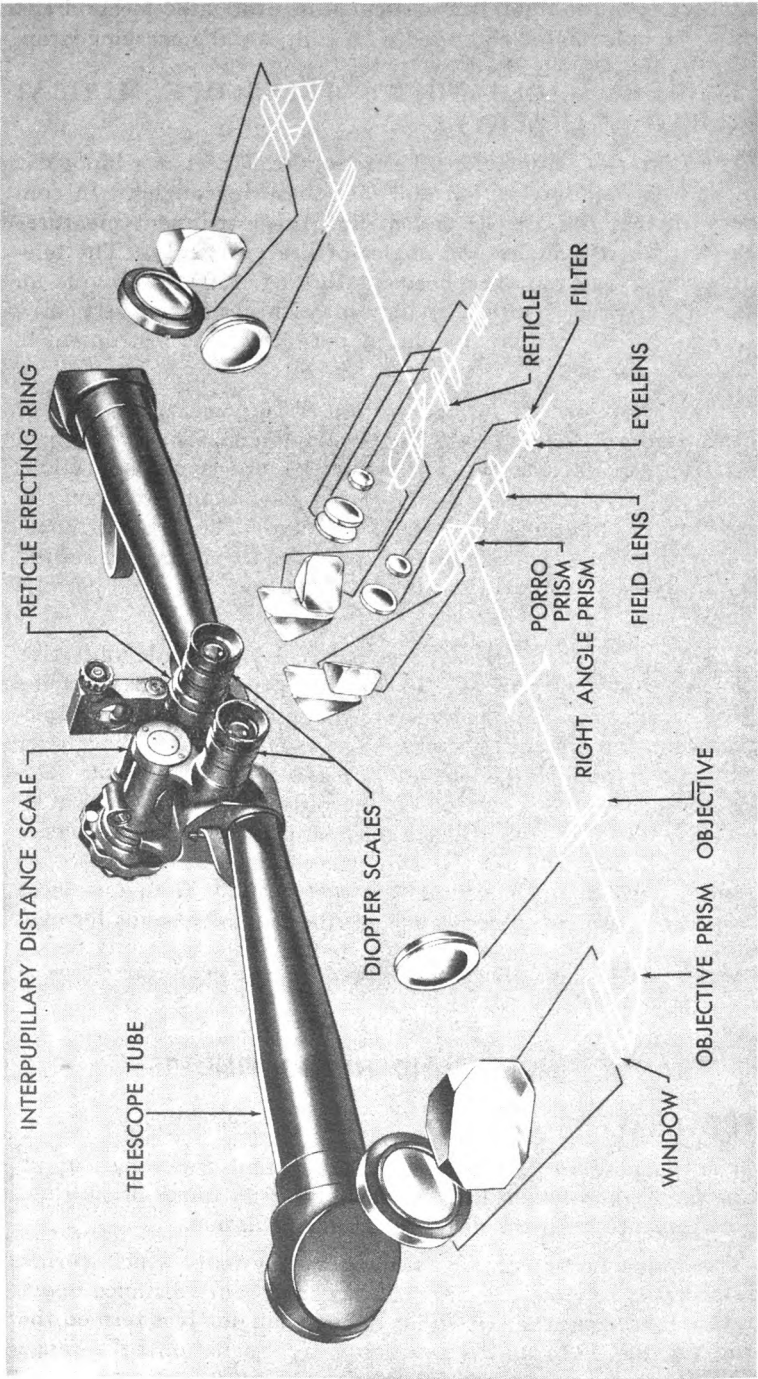
#### **105. BINOCULAR M13A1 (GENERAL USE).**

a. The Binocular M13A1 (fig. 129) is a general purpose instrument for use by all services. It has a magnification of 6 power, the objective diameter is 30 millimeters, and the field of view is 8 degrees 30 minutes. Each of the prism offset type telescopes has an achromatic objective and a Kellner type eyepiece with a compound eyelens and a plano-convex field lens. A Porro prism erecting system is employed in each telescope. The eyepieces are individually adjustable from plus 4 to minus 4 diopters to meet eyesight variations. Graduated diopter scales permit prefocusing of both eyepieces. The interpupillary distance adjustment also is provided with graduations to permit presetting.

b. A reticle is included in the optical system for the left eye. The horizontal scale of this reticle pattern (fig. 101) is graduated in mils. Above the center and on the left-hand portion are reference marks



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Figure 131 — BC Telescope M1915A1 — Assembled View, Optical Elements, and Optical Diagram

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spaced 5 mils apart for convenience in observing fire. Crossing this horizontal scale, to the right, is a vertical scale graduated in hundreds of yards. The binocular is equipped with a filter and a carrying strap.

#### **106. BATTERY COMMANDER'S TELESCOPE M1915A1 (FIELD ARTILLERY).**

a. The Battery Commander's Telescope M1915A1 is a binocular instrument used for observation and for measuring angles. In conjunction with the tripod head and mount, the instrument measures azimuth (horizontal) angles and angles of site (vertical). The telescope tubes may be positioned horizontally (fig. 130) to provide an accentuated stereoscopic effect, or they may be positioned vertically, with the eyes below the line of sighting, permitting the instrument to be used as a periscope.

b. This instrument has a magnification of 10 power and a field of view of 4 degrees 15 minutes. The two telescopes have identical periscopic type optical systems. The right telescope contains a reticle. The reticle is provided with a rotating ring for erecting it when the telescopes are in horizontal or vertical position. The hinge arrangement which connects the two telescopes provides for the proper setting of the interpupillary distances of individual observers; a scale permits presetting.

c. The head of each telescope contains a right-angle objective prism protected by a window (fig. 131). Porro prism systems erect the images. The achromatic objectives are mounted between the objective prisms and the erecting systems. The eyepieces of Kellner type each contain a compound eyelens and a plano-convex field lens. Detachable sunshades may be fitted on the objective ends of the telescopes, and detachable amber filters may be placed on the eyepieces when required. Leather objective caps are attached to the telescopes for installation when the instrument is not in use. Both eyepieces have diopter adjustment to accommodate the optical systems for eyesight variations.

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### **Section VI**

## **RANGE FINDERS AND HEIGHT FINDERS**

### **107. GENERAL.**

a. The purpose of a range finder is to find the range of an object or target; the height finder gages either its range or altitude. These instruments measure distance by triangulation.

b. The range finder contains two optical systems which permit a single observer to view the target from points some distance apart. This distance serves as the known leg of the triangle. It is termed the *base line* (A, fig. 132) and is one form of designation of a range



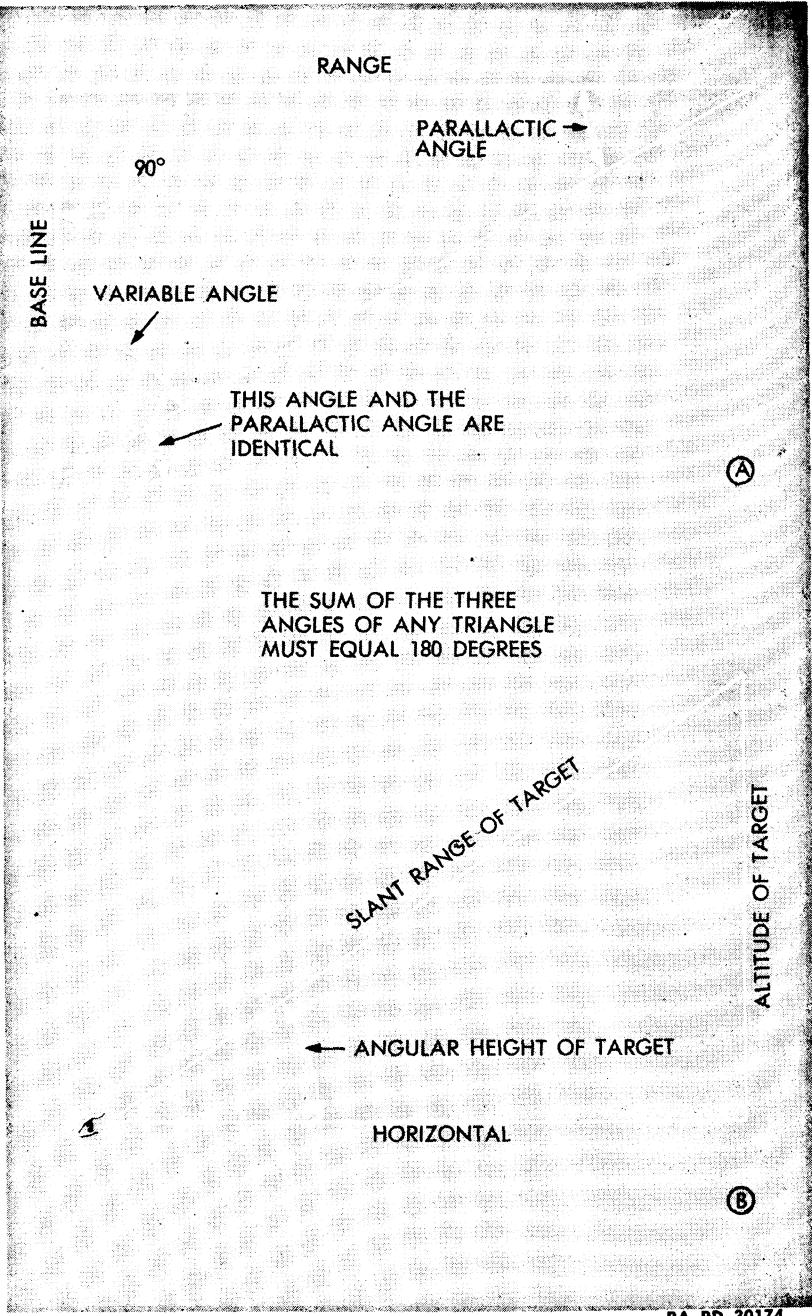


Figure 132 — Fundamental Triangles of Range Finder (A) and Height Finder (B)

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finder, that is, a 1-meter base instrument. One of the two angles from which the target is observed is fixed at 90 degrees; the other angle is variable, depending upon the distance of the target from the instrument. The angle to which the 90-degree and the variable angle converge is termed the *parallactic angle*. It becomes larger as the distance to the observed object becomes less. Because of the extreme shortness of the base line in comparison with the range to be computed, the utmost accuracy and precision are required in the determination of the angles at the two ends of the base line.

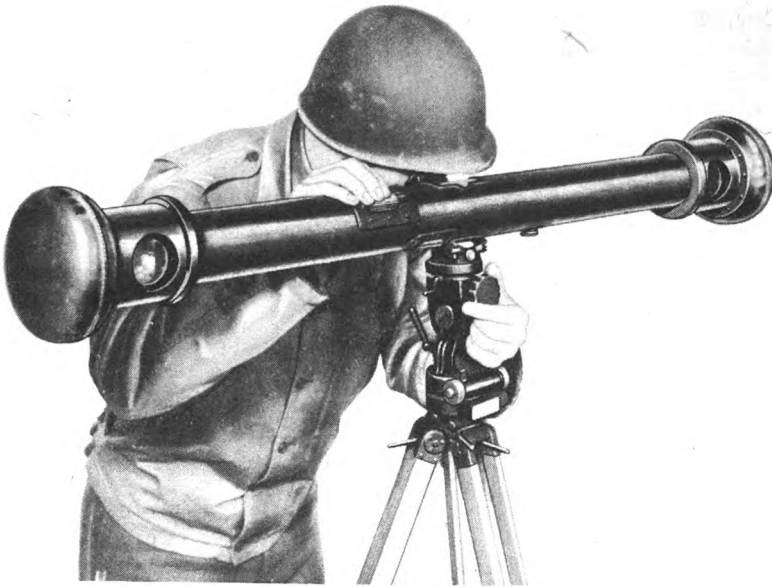
c. A height finder measures altitude by solving a vertical triangle. In this case, the slant range to the target (B, fig. 132) as determined by the observer is multiplied by the sine of the angular height. The multiplication is performed mechanically or optically.

d. The optical system of the coincidence range finder causes the images entering the two ends of the instrument to coincide or combine in a centrally located image plane, and form two half images which are viewed through a single eyepiece.

(1) Certain instruments of this type form two half images which, except for a dividing or *halving line*, appear formed by a single objective. This is known as the *erect type* image. On other instruments for two half images, the upper half is inverted and appears to be the mirrored image of the lower half. This is known as the *invert type* image. When perfect halving and coincidence have been secured in either type, the range is indicated on the range scale. The erect type of field is usually preferred when the target is of a regular geometrical shape with well defined boundaries. The inverted type is considered to have advantages when the target is poorly defined or very irregular in shape, as where the targets sighted upon may be trees or trench parapets.

(2) There are two types of coincidence range finders which operate on different principles. In instruments of one design, a measuring wedge (par. 97) is employed to deviate the rays of light. This wedge is moved backward or forward in the line of sight until coincidence is secured. In the other design (known as the *azimuth type*) the right and left objectives have slightly different powers of magnification. Swinging the instrument in azimuth about its vertical axis causes the erect and inverted half images to traverse the field at slightly different rates so that coincidence for an object or target at any given range is obtained at only one location in the field.

e. The stereoscopic range and height finder may be considered as a binocular telescope, fitted with reticles for measuring distance and with the objectives located at a considerable distance from one another. This increased interobjective distance combined with high magnification greatly accentuates stereo-vision. Each of the two optical systems form a complete image. The two images are viewed with both eyes of the observer through a pair of eyepieces and fused into a single image by his brain in the same manner as in normal



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**Figure 133 — 1-Meter Base Range Finder M1916 — In Use**

binocular vision. The line of sight through the variable angle end of the instrument is deviated by a system of rotating wedges (par. 68 f). A reticle in each optical system of the instrument places a reference pattern in the focal plane of each eye. These patterns appear to fuse into a single pattern in relief when viewed at once by both eyes. The center of the pattern can be brought exactly onto the fused target image by moving the rotating wedges. This is termed *stereoscopic contact*. The motion of the rotating wedges is mechanically transmitted to a calibrated scale or range drum, and the range can be read directly on the scale or drum when stereoscopic contact has been established.

#### **108. RANGE FINDER, 1-METER BASE, M1916 (FIELD ARTILLERY).**

a. The 1-meter Base Range Finder M1916 (fig. 133) is of the measuring wedge coincidence type producing an invert image. Coincidence is obtained by turning a range drum knob until the half images of the point selected appear in coincidence. The range in yards is read on the range drum against the sliding range pointer. This instrument has a magnifying power of 15 and a field of view of 3 degrees 10 minutes.

b. Light enters the front side of the two ends of the instrument through the end box windows and is bent at right angles by the

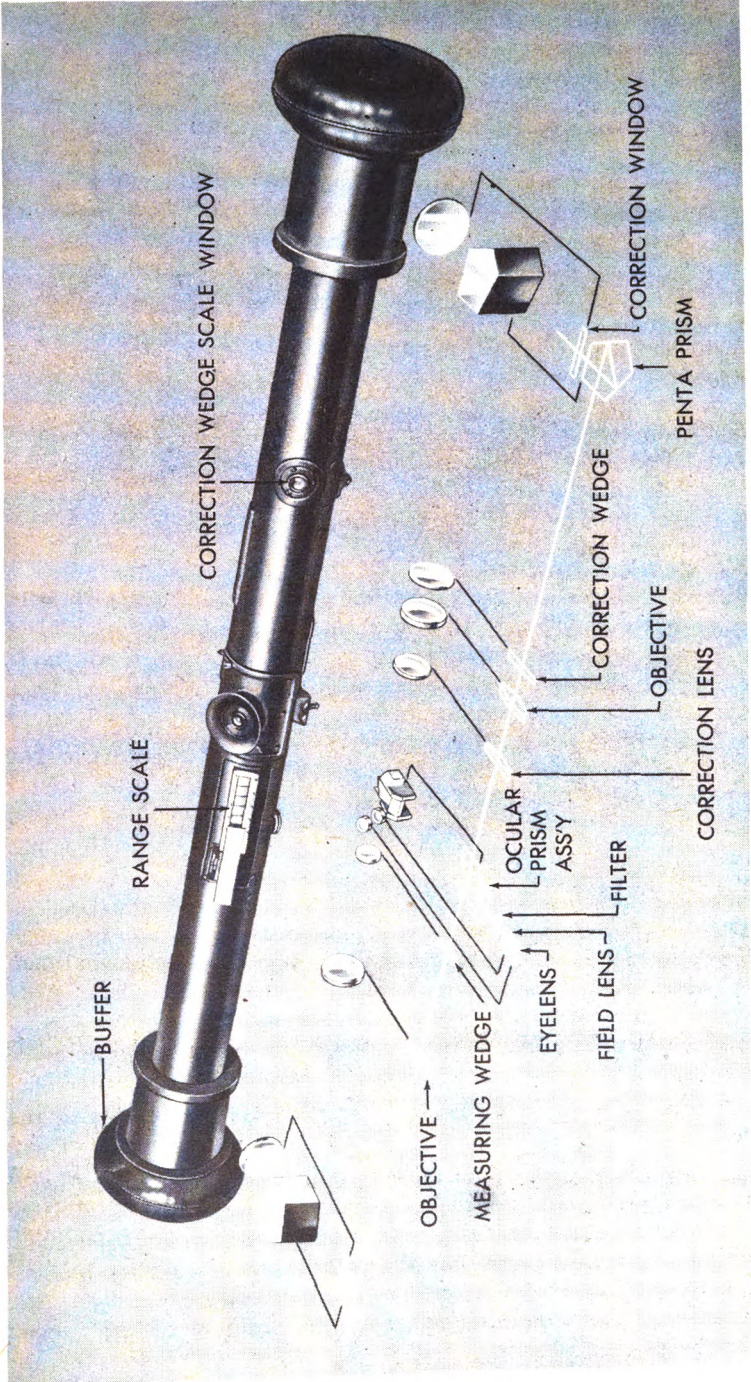


Figure 134 — 1-Meter Base Range Finder M1916 — Assembled View, Optical Elements, and Optical Diagram

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penta prisms toward the centrally located eyepiece (fig. 134). The end box windows are optical wedges which are carefully adjusted in manufacture to compensate for combined deviations of the optical system. End box sleeves can be rotated to cover the window openings for protection against breakage and dirt. Padded leather buffers on the ends of the instrument afford protection against minor shocks.

c. The two objectives, measuring wedge, correction lens, and ocular prism assembly are mounted in a separate optical tube within the outside tube. The optical tube is supported at the ends. One of the supports provides for adjustment in height for the proper position of the half images at the halving line. The objectives are mounted in the ends of the optical tube.

d. The measuring wedge is mounted between the left objective and the ocular prism assembly. This wedge can be moved toward and away from the left objective. Light entering the left end box window is deflected by the measuring wedge through an angle sufficient to provide coincidence. This wedge is operated simultaneously with the range drum by the range drum knob.

e. The right-hand portion of the instrument contains the adjustment elements. These are the correction lens, located in the optical tube between the right objective and the ocular prism assembly, and the correction wedge, mounted in a separate cell, sleeve, and adapter between the right penta prism and the right objective. The correction lens is provided to insure that both objectives will have the same magnifying power. The correction wedge is used to correct optical errors in the system resulting from temperature changes, and personal errors peculiar to the individual operator in his adjustment of the instrument. The correction wedge is fitted with a shaft for adjustment and a scale to record movement. The scale is viewed through a window located to the right of the eyepiece.

f. The ocular prism assembly or coincidence prism is a system of small prisms cemented together. This assembly receives the light from both ends of the range finder, suppresses the upper half of both images, erects the lower half of one image and reverts the other, and produces these images, one inverted above the halving line, and the other erect and below it. These half images and the halving line are focused and magnified by the eyepiece when viewed by the observer.

g. The eyepiece is of symmetrical type with a compound eye-lens and a compound field lens. It is focused by rotation of a diopter scale. The eyepiece is fitted with amber and smoked ray filters controlled by a ray filter lever. The filters are kept in a filter holder located between the eyepiece and the ocular prism assembly. An open sight near the eyepiece facilitates the training of the range finder on the desired target.





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**Figure 135 — 80-cm Base Range Finder M1917 — In Use**

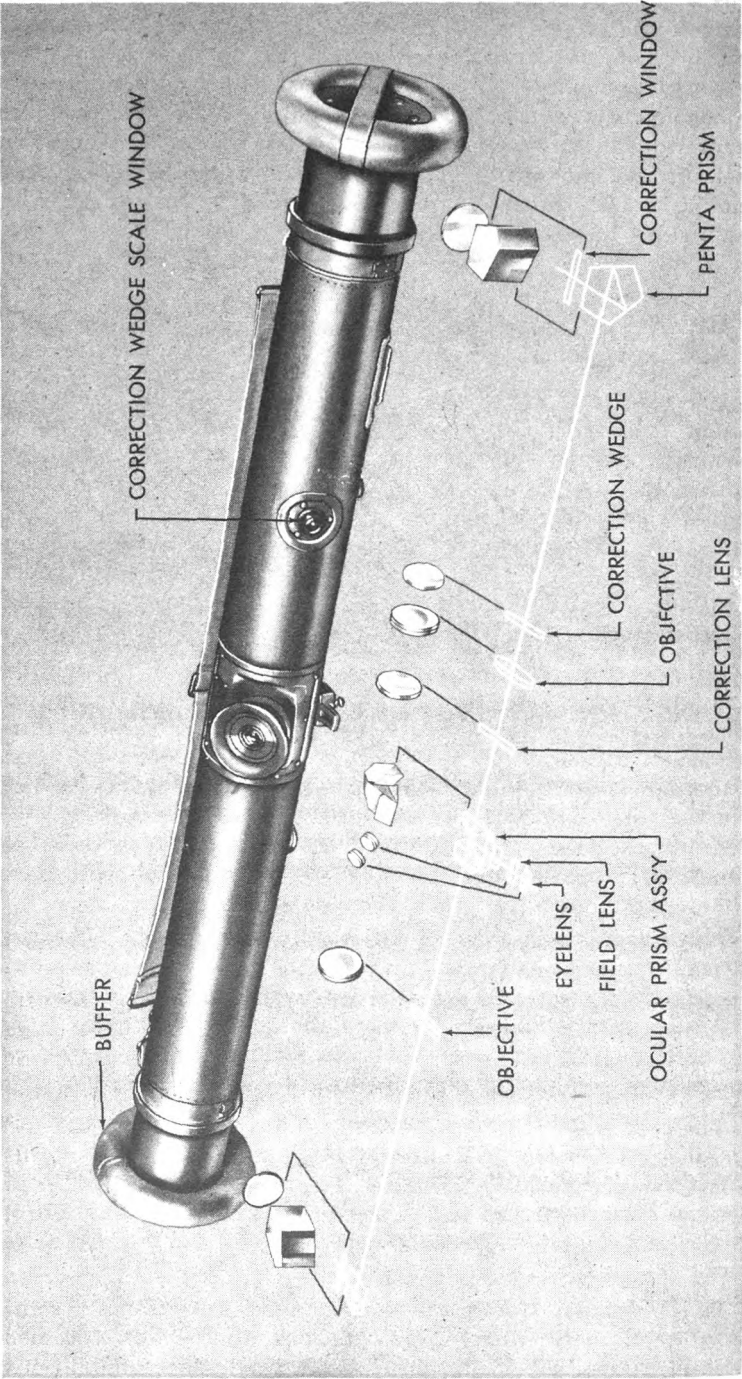
**109. RANGE FINDER, 80-CENTIMETER BASE, M1917 (INFANTRY).**

a. The 80-cm Base Range Finder M1917 (fig. 135) is of the azimuth coincidence type producing an invert image. This instrument has a magnification of 10 power and a field of view of 4 degrees 30 minutes. Its base length of 80 centimeters is approximately 31½ inches.

b. Range measurements are made with this instrument by swinging it in azimuth about its vertical axis, causing the erect and inverted half images seen through the eyepiece to traverse the field at slightly different rates. This is due to slightly different power of magnification of the right and left objectives. Coincidence for an object at a given range is obtained at only one location in the field.

c. Range measurements are read on a distance scale engraved on the reticle of the ocular prism assembly. The scale appears in the field directly below the halving line. The distance scale is graduated to show ranges of objects situated from 450 yards to an infinite distance from the instrument.

d. The optical system of this instrument (fig. 136) is very similar to that of the 1-meter Range Finder M1916A1 (par. 108), except that there is no measuring wedge or range drum, the right and left objectives differ in magnifying power from one another, the correc-



RA PD 30178  
Figure 136 — 80-cm Base Range Finder M1917 — Assembled View, Optical Elements, and Optical Diagram



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tion lens is employed to insure that the objectives differ in magnifying power to the proper degree instead of being used to secure equal magnification, and the range scale is engraved on the reticle of the ocular prism assembly. Otherwise, the end box windows, penta prisms, correction wedge, ocular prism assembly, filters, and eyepiece are generally like those in the 1-meter instrument and function essentially in the same manner; the central optical parts are mounted in a similar optical tube. The end box assemblies are fitted with rotating sleeves to cover the end windows and with buffers for protection against minor shocks.

**110. HEIGHT FINDER, 13½-FT., M1 (ANTIAIRCRAFT ARTILLERY).**

a. The 13½-ft. Height Finder M1 (fig. 137) is a self-contained instrument employing the stereoscopic principle of range finding. This instrument is normally used in an antiaircraft battery to determine the slant range or altitude of a designated aircraft target, and to transmit this data continuously to the antiaircraft director used by the battery. The conversion of slant range to altitude is accomplished by optical and mechanical means within the instrument. The instrument may be elevated from zero to 90 degrees and traversed 360 degrees.

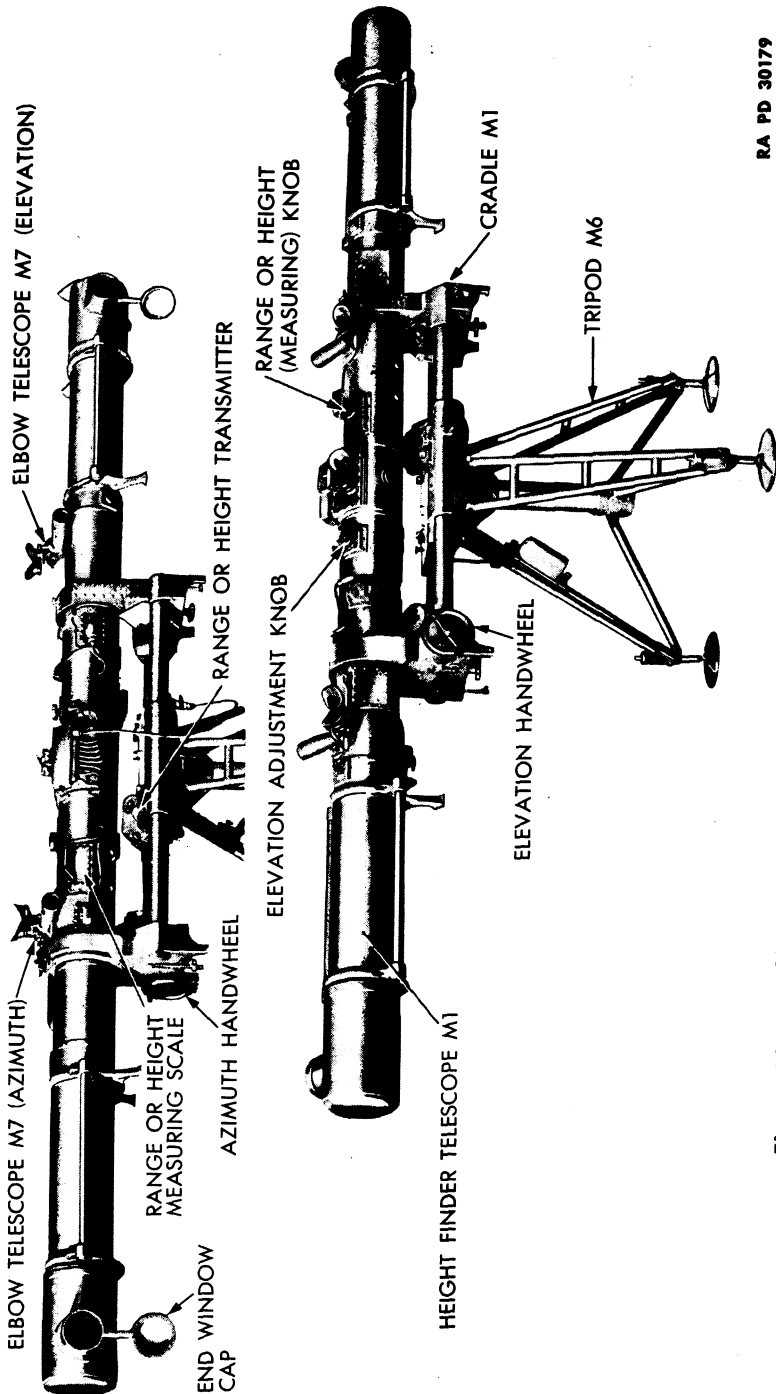
b. Range or height measurements are secured by fusing the images of the target, seen through the two eyepieces of the instrument, upon a reticle pattern. The target and reticle are seen in three dimensions with relation to one another. When the target appears to be the same distance away as the central mark of the reticle pattern, the range or height of the target can be read directly on the measuring scale of the instrument. The range or altitude measuring scale is graduated from 550 to 50,000 yards. The instrument must be preset to measure either range or height.

c. Two tracking telescopes and conveniently located handwheels are provided for a lateral (azimuth) tracker and a vertical (elevation) tracker; they keep the height finder on the target. An integral target system in the height finder permits adjustment for changes in the optical alinement of the instrument arising mainly from changes in temperature.

d. The principal optical system of the instrument is the 13½-ft. Height Finder Telescope M1 (fig. 138). It consists of two internal telescopes, one for each eye, which are used by the stereoscopic observer to view the target within the fused stereoscopic pattern of the reticles in the two telescopes. It also contains the internal target system or internal adjuster.

e. To prevent sudden changes in temperature from affecting the accuracy of the instrument by disturbing the perfect alinement of the optical parts, it is built with a double-walled, insulated body.

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RA PD 30179

Figure 137 — 13 1/2-Ft. Height Finder M1 — Assembled View — Front and Rear

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This body consists of a main tube and an outer tube of such diameters that there is a space between them. The entire instrument is hermetically sealed. The most sensitive optical parts are carried in an inner tube called an *optical bar*. These parts are the objectives, reticles, erectors, ocular prisms, and height adjustment plate. They are separated from the eyepieces by sealing glasses. The objectives are mounted in the ends of the optical bar.

f. Light enters the two end windows in the front of the two ends of the instrument and is bent toward the centrally located optical parts by the two pairs of reflectors. Pairs of reflectors or mirrors are used in place of penta prisms because of the difficulty of securing blocks of glass sufficiently large and homogeneous for the construction of such prisms. Before entering the optical tube, light from the right end window passes through the measuring wedge assembly, while light from the left end window passes through the internal adjuster correction wedge. These two elements are provided with individual mountings.

g. The measuring wedge assembly consists of four circular wedges. They are geared to be caused to rotate by two independent sources of motion. These sources of motion are the range mechanism and the conversion mechanism. Manipulation of the range or height measuring knob to cause the line of sight of the right telescope to be deviated to focus upon the target automatically causes the range and conversion mechanisms to convert target range to target height. The internal adjuster correction wedge is a single rotating wedge which deviates the line of sight of the left telescope to correct for errors due to temperature variations. The height adjustment plate is a thick glass plate with plane surfaces which, tilted to the left or right, deviates the light upwards or downwards to adjust the image of the left eyepiece to the same height as the image visible in the right eyepiece.

h. The two internal telescopes provide either 12-power or 24-power magnification as desired. Change of magnification is obtained by turning a crank which shifts the positions of the erectors with relation to the eyepieces. The rhomboid prisms in the eyepieces are mounted to rotate about the fixed centers of the ocular prisms; they permit the eyepieces to be adjusted in interpupillary distance to suit the individual observer. The interpupillary scale is graduated from 58 millimeters to 72 millimeters to permit presetting. Each eyepiece may be adjusted from plus 2 to minus 4 diopters to correct for eyesight variations. A ray filter assembly with red, amber, blue, neutral, and clear filters is provided for each eyepiece to improve visibility of the target under varying conditions of haze, glare, and camouflage; selection is made by turning a filter knob. An adjustable head rest and eyeshields relieve strain in extended observation.

i. The internal target optical system provides an artificial, infinitely distant target for use in adjusting the main optical system to

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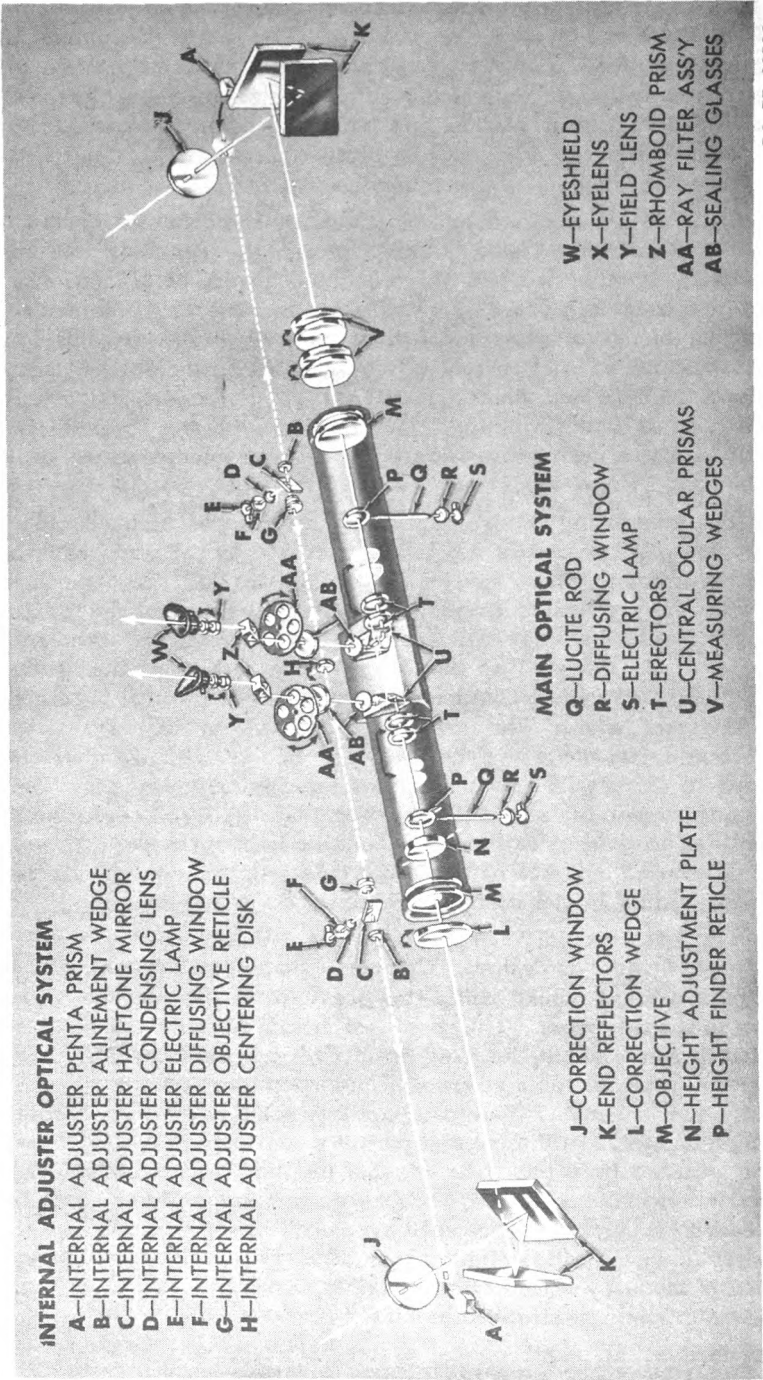


Figure 138 — 13 1/2-Ft. Height Finder Telescope M1 — Phantom View

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compensate for errors introduced by temperature changes. Each half of this system includes a diffusing window, condensing lens, half-tone reflector or mirror, objective reticle, alinement wedge, and penta prism. In addition, the system contains a centering plate or disk. A single vertical line is engraved on each objective reticle to serve as the adjuster target. The penta prisms are mounted in such manner that they may be shifted into the field when required in the adjustment procedure. Light from electric bulbs is diffused by the diffusing windows, concentrated by the condensing lenses, and strikes the half-tone reflectors. It is reflected through the objective reticle, the centering plate, and the opposite reflector to the penta prisms. The light is bent by the penta prisms into the main optical system. When viewed through the instrument, the target lines appear to be in an infinitely distant plane and may be used to determine the correct internal adjustment which is made by rotating the internal adjuster correction wedge in the main optical system. The alinement wedges and centering plate are included in the internal target optical system so that the entire system may be made optically true when assembled at the factory.

j. The tracking telescopes provided for this instrument are the Elbow Telescope M7 (azimuth) and Elbow Telescope M7 (elevation). They are identical except for the reticles which prevent their being interchangeable. The reticles are of the cross line type with the horizontal line broken at the center in the azimuth instrument and the vertical line broken in the elevation instrument. The magnification is 8-power and the field of view is 6 degrees. Each telescope is provided with diopter adjustment to accommodate for eyesight variations and a collimator peep sight for initially training on the target. A blind eyeshield is provided to rest the inactive eye of the observer; this is adjustable for interpupillary distance. The objective is protected by a sunshade.

## CHAPTER 6 – TESTING OPTICAL PROPERTIES OF INSTRUMENTS

### 111. GENERAL.

a. This section describes a number of relatively simple procedures by means of which the properties and qualities of complete instruments may be measured or calculated. For the most part, the tests can be made without special equipment. Laboratory test methods are purposely avoided.

### 112. OBJECTIVE APERTURE.

a. The objective aperture size is limited by the clear area provided by the mount of the objective. It can be measured in millimeters or decimal parts of an inch with a scale or rule.

### 113. MEASUREMENT OF EXIT PUPIL AND EYE DISTANCE.

a. Focus the exit pupil on translucent paper or ground glass. To focus the exit pupil, move the paper or glass towards or away from the eyepiece until the exit pupil is seen in its smallest diameter as a sharp circular shape of even brightness. Measure the distance of the face of the paper or glass from the eyepiece lens with a scale graduated in decimals of an inch. Mark the opposite edges of the exit pupil on the paper or glass and measure its diameter or fractions of an inch.

### 114. MAGNIFYING POWER.

a. **Calculation.** The magnifying power of an optical instrument depends upon the relation between the focal length of the objective and the focal length of the lenses of the eyepiece, the latter being considered as a single lens. For example, if the objective has an equivalent focal length of 8 inches, and the eyepiece has an equivalent focal length of 1 inch, the instrument will have a magnification of 8 power; focal length of objective divided by focal length of the eyepiece.

b. **Measurement.** The magnifying power of an instrument can be calculated when the equivalent focal lengths of the objective and the eyepiece are known. It can be determined by measuring the focal lengths of the elements. The magnifying power can be approximately determined by this method: Mark a number of connected squares of equal size in a line on a distant white wall. Observe the squares with the right eye looking through the instrument and with the left eye looking at them naturally. The right eye will receive a magnified impression of one or two of the squares; the left eye will receive a natural impression of a number of them. The two impressions will be fused by the brain into a single impression of a large square with a number of smaller ones crossing it in a line. If four natural squares are seen inside the magnified square, the instrument has a magnification of approximately 4 diameters or 4 power.

**115. MEASUREMENT OF FIELD OF VIEW.**

a. The field of view (FOV) of an instrument may be expressed in either angular or linear measure. The angular measure is more commonly given and is expressed in degrees and minutes. The linear measure is expressed in feet and yards at ranges of 100 feet, 100 yards; 1,000 feet or 1,000 yards; beyond 1,000 yards it is always expressed in yards.

b. To determine the angular FOV, place the telescope in a fixture or mount which is provided with an azimuth scale and micrometer, and levels. Level the instrument, and direct the telescope so that a convenient vertical object is at the left edge of the FOV. Read the scale and micrometer. Traverse the instrument until the object is at the right edge of the FOV. Again, read the scale and micrometer. The difference between the two readings is the angular measure of the FOV. If the scale and micrometer are graduated in mils, convert to degrees and minutes.

c. To measure the linear FOV, place two stakes at a specified distance from the instrument; one at each edge of the observed FOV. Measure the actual distance between the two stakes, and convert the measurement into the proper units (subpar. a, above). The linear FOV may be determined mathematically by the formula:  $2 \times \tan$  gent of one-half the angular FOV  $\times$  the range of the stakes.

**116. MEASUREMENT OF SPHERICAL ABERRATION.**

a. Cut a mask of black paper that will cover the objective. Cut a circle, one-half the diameter of the objective, out of the center of this mask. Apply the mask to the objective. Sharply focus a distant object on the cross line of the instrument. Now, remove the mask and place the cut-out circle on the center of the objective. Examine the image of the object. Any blurring of the image may be attributed to unfocused rays in the outer zones of the objective. Adjust whatever focusing devices there are available to sharply focus the image. The amount of movement required is a measure of the amount of spherical aberration present.

**117. MEASUREMENT OF CURVATURE OF FIELD.**

a. Sharply focus the instrument on a point in the center of the field and note whether or not the points at the edge of the field are clear and well defined. If the edges of the field are hazy, continue focusing the instrument until the edges of the field are sharp and distinct. The amount of focusing required is an indication of the curvature.



## CHAPTER 7 — MEASUREMENT SYSTEMS EMPLOYED IN OPTICS

### 118. CANDLEPOWER AND FOOT CANDLES.

a. The intensity of illumination on a surface depends upon the brightness of the light source and the distance of the surface from the light source. The brightness of any light source is measured in units of *candlepower*. One candlepower is the rate at which a standard candle emits light. A standard candle was initially a sperm whale oil candle,  $\frac{7}{8}$  inch in diameter, which burned at the uniform rate of 120 grains per hour. Current standards of candlepower are electric lamps which may be obtained from the Bureau of Standards.

b. The amount of illumination on any surface depends upon the distance of the surface from the light source. A candle 1 foot away from a screen will shed more intense light on a given area of the screen than it would if it were 3 feet from the screen. In the latter case, it would illuminate a larger area with less intensity. The intensity of illumination is measured in *foot candles*. A foot candle is the amount of light received on a surface 1 foot away from a light source of 1 candlepower.

### 119. DIOPTERS.

a. The *lens diopter* or, simply, *diopter* is the unit of measure of the refractive power of a lens or lens system. The *prism diopter* is the unit of measure of the refracting power of a prism. Both are based on the metric system of measurement.

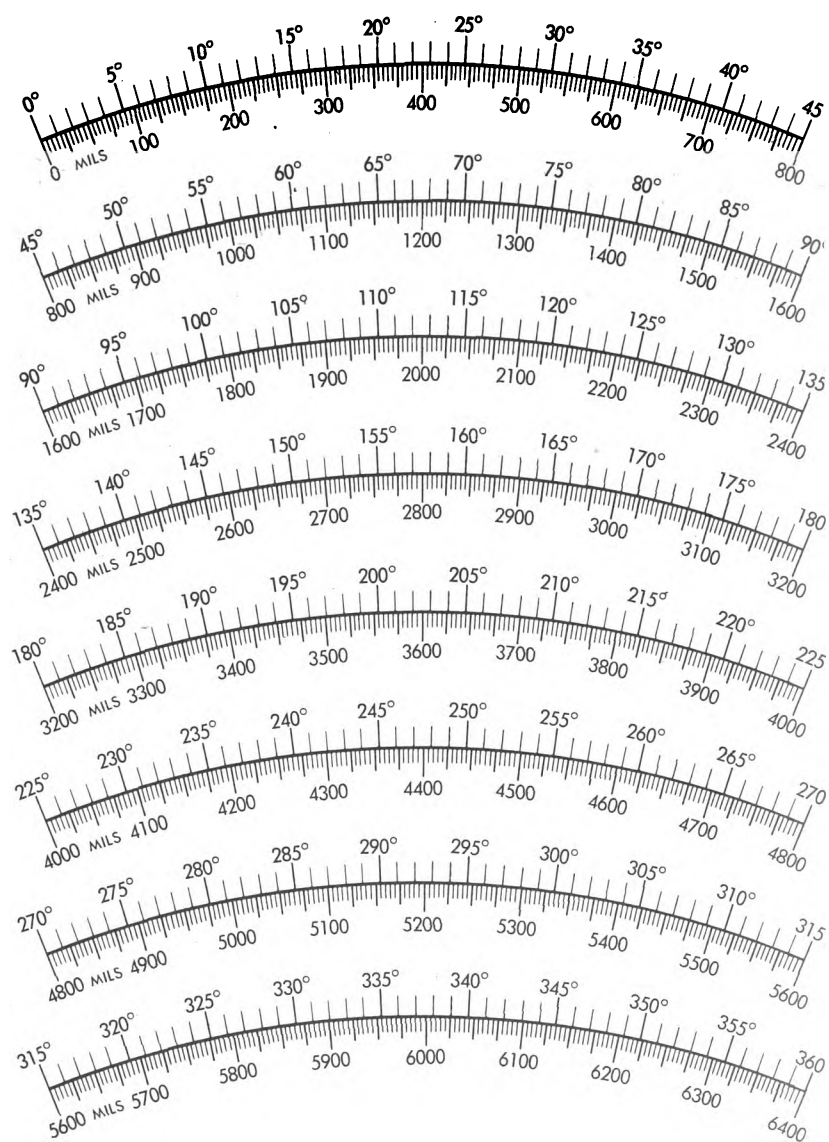
b. **Lens Diopter.** A lens with a focal length of 1 meter is internationally recognized to have the power of 1 *diopter*. The power of a converging lens is *positive* and that of a diverging lens is *negative*. The power of other lenses than those of 1-meter focal length is the reciprocal of the focal length in meters and varies inversely as the focal length. This means that a converging lens with a focal length of 20 centimeters or  $\frac{1}{5}$  meter has a power of +5 diopters, while a diverging lens with a focal length of 50 centimeters or  $\frac{1}{2}$  meter has a power of -2 diopters. The lens with the shortest focal length has the greatest plus or minus power in diopters.

c. **Prism Diopter.** A prism with a power of 1 prism diopter will deviate light by 1 centimeter at a distance of 1 meter from the prism. Thus, the prism diopter designation of a refracting prism is the measurement of the amount it can bend light. A 2-diopter prism will bend light twice as far as a 1-diopter prism.

### 120. DEGREE SYSTEM.

a. The degree system is a means of measuring and designating angles or arcs. The degree is  $\frac{1}{360}$  part of a circle or the value of

*Measurement Systems Employed In Optics*



RA PD 30181

**Figure 139 — Mil-Degree Conversion Chart**

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*Measurement Systems Employed in Optics*

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the angle formed by dividing a right angle into 90 equal parts. Each degree is divided into 60 parts called minutes, and each minute into 60 parts called seconds.

b. In the use of fire control equipment, either degrees or mils (par. 121) may be used to designate angles of elevation and azimuth. One degree equals 17.78 mils. One mil equals 0.056 degree, or 3 minutes 22½ seconds. Refer to the conversion table (fig. 139) for the approximate relative values of given angles of elevation and azimuth in degrees and mils.

### 121. MIL SYSTEM.

a. The mil system is a means of angular measurement that lends itself to simple mental arithmetic. It provides accuracy within the limits demanded by the military forces with distinct advantages of simplicity and convenience not afforded by any other method of angular measurement. It is based on an arbitrary unit of measurement known as the *mil*. The mil is exactly  $\frac{1}{6400}$  of a complete circle.

b. The mil is very nearly the angle between two lines which will enclose a distance of 1 yard at a range of 1,000 yards. Exact computation of the distance enclosed at 1,000 yards by 1 mil gives the result of 0.982 yard. Therefore, in assuming that 1 mil encloses 1 yard at 1,000 yards, an error of 0.018 yard or 0.65 inch is introduced. This error is negligible for all practical purposes.

c. A circle of 1,000 yards radius would have a circumference of 6,283 yards. A 1-yard portion of the circumference would be the  $\frac{1}{6283}$  fractional part of a circle. By choosing the mil as the  $\frac{1}{6400}$  fractional part of a circle, sufficient accuracy is retained for all practical purposes, while the number can be handled easily by mental arithmetic.

d. The mil provides an extremely small unit of angular measurement that is easily adaptable to the small angles encountered by the artilleryman. For example, if an object has an angular width or height of 1 mil, it is 1 yard wide or high at 1,000 yards; 2 yards wide or high at 2,000 yards; and so on. A man is approximately 2 mils tall at 1,000 yards, or 1 mil tall at 2,000 yards.

**NOTE:** *The Navy mil and the French infantry mil are exactly the angle between two lines which will enclose a distance of 1 yard at a range of 1,000 yards. There are 6283.1853 Navy or French infantry mils in a complete circle.*

e. For quick, approximate conversion from artillery mils to degrees, or vice versa, refer to figure 139. On this chart, locate the number or degrees or mils to be converted. Directly across the black line of arc is its equivalent.

f. For more exact conversion from mils to degrees, minutes, and seconds, use this conversion table:

Measurement Systems Employed in Optics

| Mils       | Degrees | Minutes | Seconds |
|------------|---------|---------|---------|
| 1 .....    | 0       | 3       | 22.5    |
| 2 .....    | 0       | 6       | 45      |
| 3 .....    | 0       | 10      | 7.5     |
| 4 .....    | 0       | 13      | 30      |
| 5 .....    | 0       | 16      | 52.5    |
| 6 .....    | 0       | 20      | 15      |
| 7 .....    | 0       | 23      | 37.5    |
| 8 .....    | 0       | 27      | 0       |
| 9 .....    | 0       | 30      | 22.5    |
| 10 .....   | 0       | 33      | 45      |
| 20 .....   | 1       | 7       | 30      |
| 30 .....   | 1       | 41      | 15      |
| 40 .....   | 2       | 15      | 0       |
| 50 .....   | 2       | 48      | 45      |
| 60 .....   | 3       | 22      | 30      |
| 70 .....   | 3       | 56      | 15      |
| 80 .....   | 4       | 30      | 0       |
| 90 .....   | 5       | 3       | 45      |
| 100 .....  | 5       | 37      | 30      |
| 200 .....  | 11      | 15      | 0       |
| 300 .....  | 16      | 52      | 30      |
| 400 .....  | 22      | 30      | 0       |
| 500 .....  | 28      | 7       | 30      |
| 600 .....  | 33      | 45      | 0       |
| 700 .....  | 39      | 22      | 30      |
| 800 .....  | 45      | 0       | 0       |
| 900 .....  | 50      | 37      | 30      |
| 1000 ..... | 56      | 15      | 0       |
| 2000 ..... | 112     | 30      | 0       |
| 3000 ..... | 168     | 45      | 0       |
| 4000 ..... | 225     | 0       | 0       |
| 5000 ..... | 281     | 15      | 0       |
| 6000 ..... | 337     | 30      | 0       |
| 6400 ..... | 360     | 0       | 0       |

For example, to convert 2569 mils:

|             |      |      |       |
|-------------|------|------|-------|
| 2000 mils = | 112° | 30′  | 0″    |
| 500 mils =  | 28°  | 7′   | 30″   |
| 60 mils =   | 3°   | 22′  | 30″   |
| 9 mils =    | 0°   | 30′  | 22.5″ |
|             |      | —    | —     |
|             |      | 143° | 89′   |
| 2569 mils = | 144° | 30′  | 22.5″ |

g. For more exact conversion from degrees and minutes to mils, use this conversion table:

| Degrees | Minutes | Mils    |
|---------|---------|---------|
| 0       | 1       | .30     |
| 0       | 2       | .59     |
| 0       | 3       | .89     |
| 0       | 4       | 1.19    |
| 0       | 5       | 1.48    |
| 0       | 6       | 1.78    |
| 0       | 7       | 2.07    |
| 0       | 8       | 2.37    |
| 0       | 9       | 2.76    |
| 0       | 10      | 2.96    |
| 0       | 20      | 5.93    |
| 0       | 30      | 8.89    |
| 0       | 40      | 11.85   |
| 0       | 50      | 14.82   |
| 1       | 0       | 17.78   |
| 2       | 0       | 35.56   |
| 3       | 0       | 53.33   |
| 4       | 0       | 71.11   |
| 5       | 0       | 88.89   |
| 6       | 0       | 106.67  |
| 7       | 0       | 124.44  |
| 8       | 0       | 142.22  |
| 9       | 0       | 160.00  |
| 10      | 0       | 177.78  |
| 20      | 0       | 355.56  |
| 30      | 0       | 533.33  |
| 40      | 0       | 711.11  |
| 50      | 0       | 888.89  |
| 60      | 0       | 1066.67 |
| 70      | 0       | 1244.44 |
| 80      | 0       | 1422.22 |
| 90      | 0       | 1600.00 |
| 100     | 0       | 1777.78 |
| 200     | 0       | 3555.56 |
| 300     | 0       | 5333.33 |
| 360     | 0       | 6400.00 |

For example, to convert 78° 43':

70° 0' = 1244.44

8° 0' = 142.22

0° 40' = 11.85

0° 3' = .89

78° 43' = 1399.40 Mils

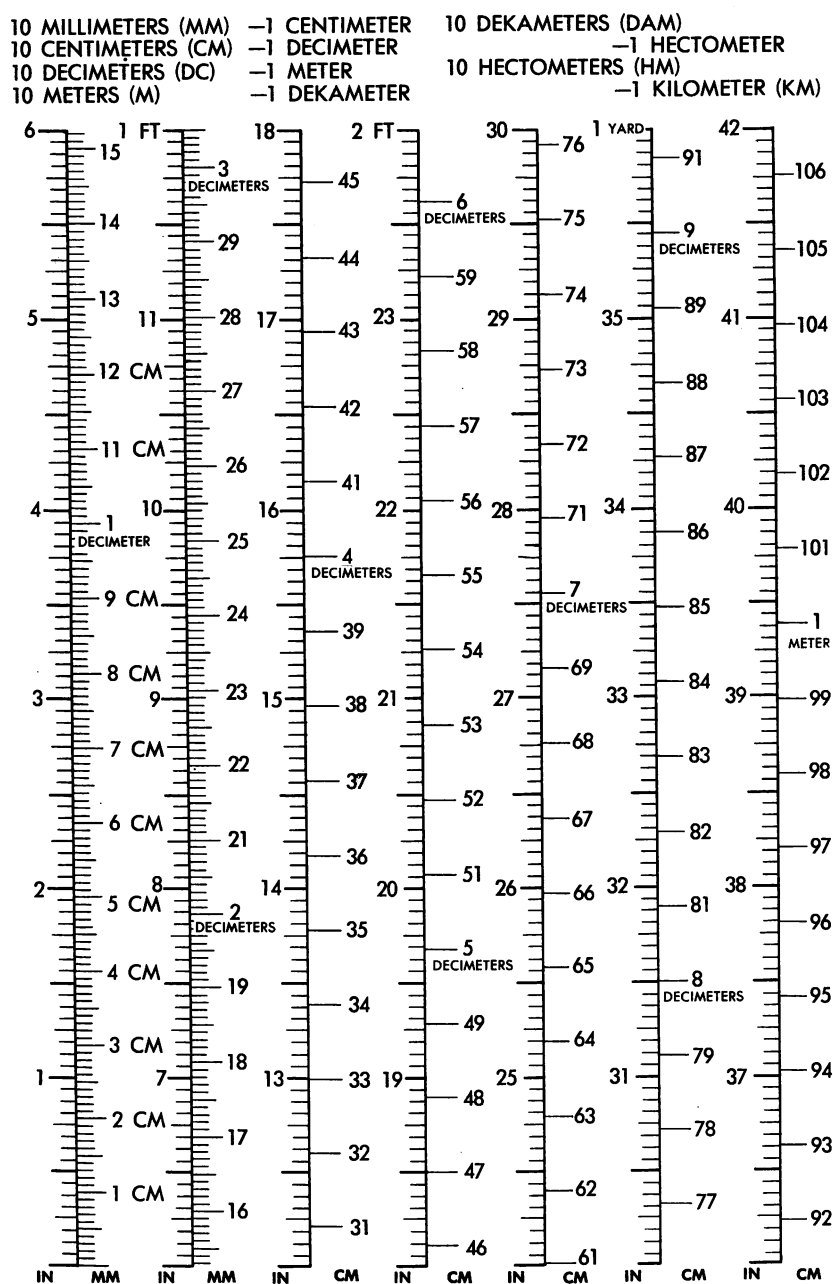


Figure 140 — Millimeter-Inch Conversion Table

Measurement Systems Employed in Optics

122. METRIC SYSTEM.

a. The meter, which is the basis of the metric system, is intended to be one ten-millionth of the distance from the equator to the pole, measured on the meridan of the earth. All units of linear measurement of the metric system are multiples or divisors of the meter in units of 10. It is a system based on decimals which provides ease of conversion from one to another of the various units of the system. Units of measurement are provided from the extremely small to the very large, inasmuch as they include the physical units of measure of the micron, millimicron, Angstrom Unit, and X-ray Unit.

b. One meter is equal to 39.37 inches. Following is a table of metric units with their equivalents in inches, yards, and miles:

|                |   |              |   |              |
|----------------|---|--------------|---|--------------|
|                |   | 1 millimeter | = | 0.03937 inch |
| 10 millimeters | = | 1 centimeter | = | 0.0937 inch  |
| 10 centimeters | = | 1 decimeter  | = | 3.937 inches |
| 10 decimeters  | = | 1 meter      | = | 1.0936 yards |
| 10 meters      | = | 1 dekameter  | = | 10.936 yards |
| 10 dekameters  | = | 1 hectometer | = | 109.36 yards |
| 10 hectometers | = | 1 kilometer  | = | 0.6214 mile  |

c. One inch equals 25.4 millimeters. One foot equals 30.48 centimeters. One yard equals 0.914 meter. One mile equals 1.609 kilometers. For approximate conversion of millimeters to inches, or vice versa, refer to the conversion table (fig. 140).

d. For more exact conversion and for conversion of large units, use the following factors to convert:

| From        | To          | Multiply              |
|-------------|-------------|-----------------------|
| Millimeters | Inches      | Millimeters by 0.0394 |
| Inches      | Millimeters | Inches by 25.4        |
| Meters      | Inches      | Meters by 39.37       |
| Meters      | Yards       | Meters by 1.094       |
| Inches      | Meters      | Inches by 0.0254      |
| Yards       | Meters      | Yards by 0.9144       |
| Kilometers  | Miles       | Kilometers by 0.6214  |
| Miles       | Kilometers  | Miles by 1.609        |

e. For quick, approximate conversion from inches to millimeters or centimeters, or vice versa, refer to figure 140. On this table, locate the measurement to be converted. Directly across the black line is its equivalent.



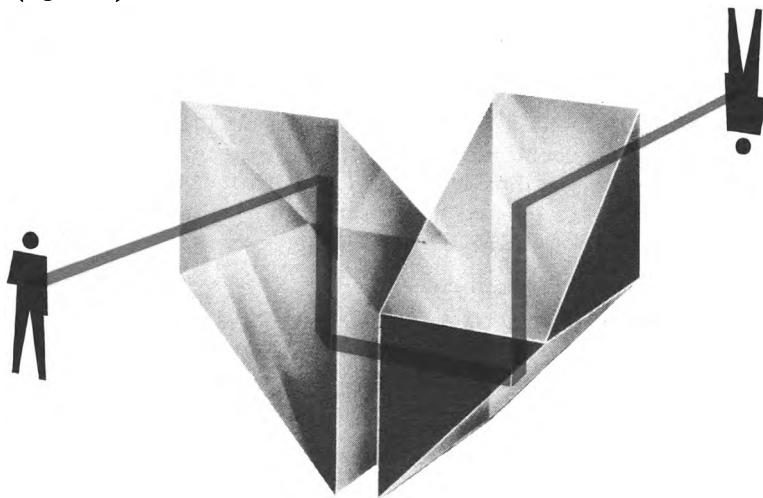
## CHAPTER 8 – GLOSSARY

### 123. GENERAL.

a. This chapter contains specialized definitions of a number of terms found in the study of optics, in the use of sighting and fire control equipment, and with reference to the eyes and vision. It includes definitions of the more unusual words used in this manual. The majority of the *italicized* words in this manual will be found in this glossary. When in doubt as to the meaning of a word, refer to this glossary.

### 124. GLOSSARY.

**ABBE PRISM ERECTING SYSTEM.** A prism erecting system in which there are four reflections to completely erect the image. It is composed of two double right-angle prisms which bend the path of light 360 deg, displacing but not deviating the path of light (fig. 141).

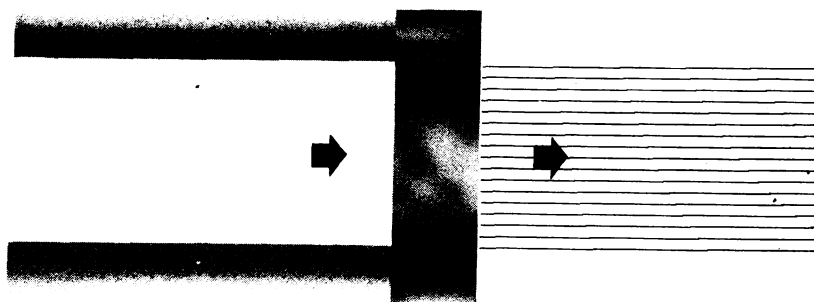


RA PD 30535

**Figure 141 – Abbe Prism Erecting System**

**ABERRATION.** Any defect of a lens or optical system which causes the image to be imperfect. See **ASTIGMATISM**; **CHROMATIC ABERRATION**; **COMA**; **CURVATURE OF FIELD**; **DISTORTION**; **SPHERICAL ABERRATION**.

**ABSORPTION.** The act or process by which an object or substance “takes up” or “soaks up” all the colors contained in a beam of white light except those colors which it reflects or transmits. Because of absorption, objects appear to have different colors; white objects have little absorption; other objects having varying powers



RA PD 30536

**Figure 142 — Absorption — Selective Transmission**

of absorption appear to have different colors. For example, an object which appears red has absorbed all the colors of the spectrum except the color red. This is known as *selective absorption*. A piece of ruby glass, placed between the eye and a source of white light, allows only red light to pass through because it absorbs all other colors. This is called *selective transmission* (fig. 142).

**ACCOMMODATION.** Automatic adjustment of the lenses of the human eye for seeing objects at different distances. The process whereby the crystalline lens is adjusted to focus sharp successive images of objects located at various distances from the eye. See **LIMITS OF ACCOMMODATION**.

**ACHROMATIC.** Without color.

**ACHROMATIC LENS.** A lens consisting of two or more elements, usually made of crown and flint glass, which has been corrected for chromatic aberration with respect to two selected colors or wave lengths of light. See **COMPOUND LENS**.

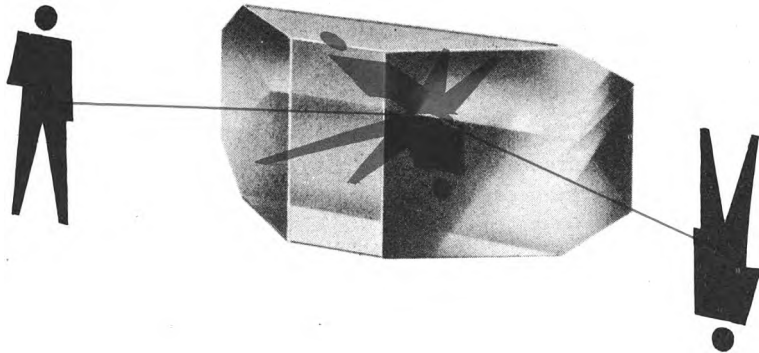
**ACUITY.** Keeness; sharpness. See **STEREO-ACUITY**; **VISUAL ACUITY**.

**ADAPTER.** A tube, ring, or specially formed part which serves to fit or connect one part with another.

**AIMING CIRCLE.** An instrument for measuring angles in azimuth and site and for general topographic work.

**AIMING POINT.** The point on which the gunner sights when aiming the gun. This point is not necessarily the target itself.

**AMETROPIA.** Any abnormal condition of the seeing power of the eyes, such as *farsightedness* (hypermetropia), *nearsightedness* (myopia), or *astigmatism*. An ametropic eye is one which, in a state of rest, does not form distinct images of objects on its retina.



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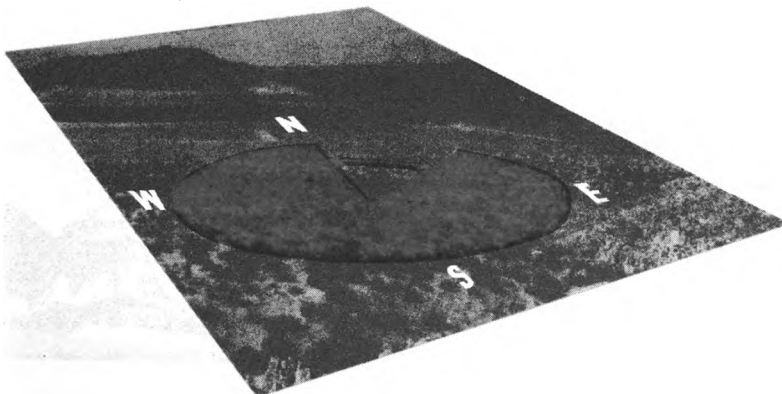
**Figure 143 — Amici Prism**

**AMICI PRISM.** Also called "roof prism" and "right-angle prism with roof." A form of roof prism designed by G. B. Amici, consisting of a roof edge formed upon the long reflecting face of a right-angle prism (fig. 143). Used as an erecting system in elbow and panoramic telescopes. It erects the image and bends the line of sight through a 90-degree angle.

**ANASTIGMAT.** A compound lens corrected for *astigmatism*.

**ANGLE.** The amount of rotation of a line around the point of its intersection with another, necessary to bring it into coincidence with the second line.

**ANGLE OF AZIMUTH.** An angle measured clockwise in a horizontal plane, usually from north (fig. 144). (The north used may be *True North*, *Y-North*, or *Magnetic North*.)



RA PD 30538

**Figure 144 — Angle of Azimuth**

Glossary

**ANGLE OF CONVERGENCE.** Angle formed by the lines of sight of both eyes in focusing on any line, corner, surface, or part of an object. Also referred to as *convergence angle*.

**ANGLE OF DEVIATION.** The angle through which a ray of light is bent by a refracting surface; the angle between the subtended path of an *incident ray* and the *refracted ray* (fig. 145).

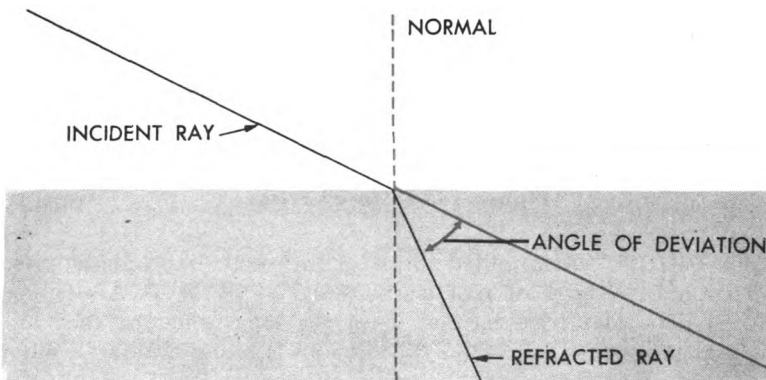
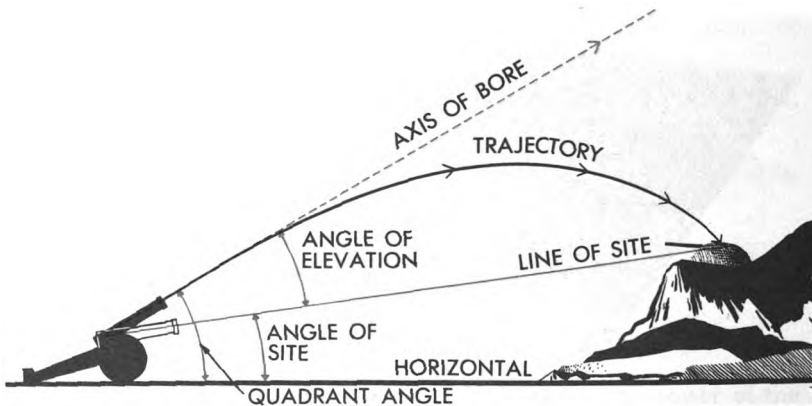


Figure 145 — Angle of Deviation

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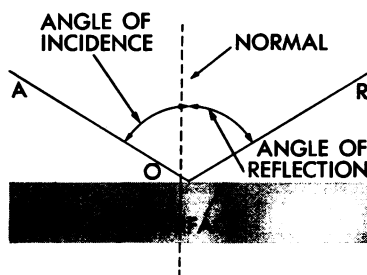
**ANGLE OF ELEVATION.** The angle between the *line of site* (line from gun to target) and *line of elevation* (axis of bore when gun is in firing position) (fig. 146). The quadrant angle of elevation is the angle between the horizontal and the line of elevation. Angle of elevation plus angle of site equals *quadrant angle of elevation*.



RA PD 30540

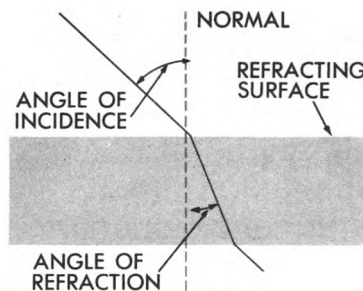
Figure 146 — Angle of Elevation, Angle of Site, and Quadrant Angle

## Glossary



RA PD 30541

Figure 147 — Angle of Incidence and Angle of Reflection



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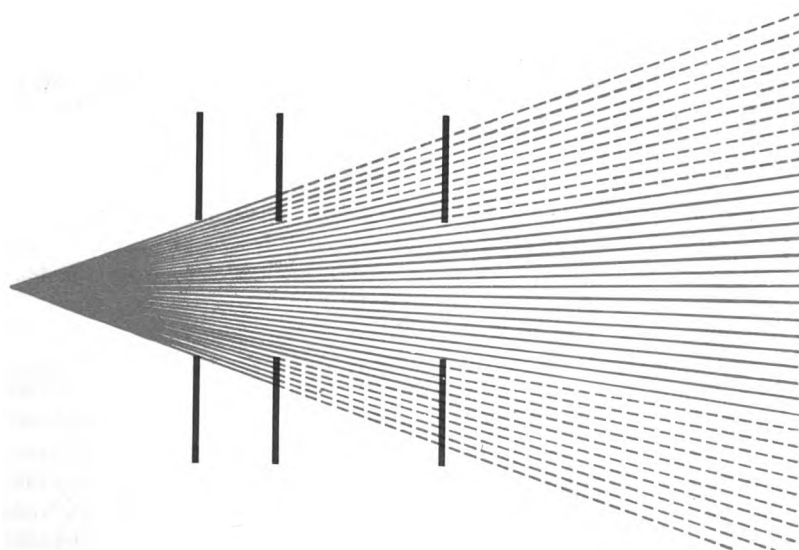
Figure 148 — Angle of Incidence and Angle of Refraction

**ANGLE OF INCIDENCE.** The angle between the *normal* to a reflecting or refracting surface and the *incident ray* (figs. 147 and 148).

**ANGLE OF REFLECTION.** The angle between the *normal* to a reflecting surface and the *reflected ray* (fig. 147).

**ANGLE OF REFRACTION.** The angle between the *normal* to the refracting surface at the point of contact and the *refracted ray* (fig. 148).

**ANGLE OF SITE.** The vertical angle between the horizontal and the *line of site* (line from gun to target) (fig. 146).



RA PD 30543

Figure 149 — Apertures

**ANGULAR.** Composed of, or measured by, angles.

**APERTURE.** An opening or hole through which light or matter may pass. In an optical system, it is equal to the diameter of the largest entering beam of light which can travel completely through the system. This may or may not be equal to the aperture of the objective (fig. 149).

**APERTURE OF OBJECTIVE.** The diameter of that part of the objective which is not covered by the mounting.

**APERTURE STOP.** The diaphragm which limits the size of the aperture. See **DIAPHRAGM**.

**APLANATIC LENS.** A lens which has been corrected for spherical aberration and coma. It may be, and usually is, also corrected for color.

**APOCHROMATIC LENS.** A lens, usually consisting of three components of different kinds of glass (two crown glass elements, one flint glass element), which has been corrected for chromatic aberration with respect to three selected colors or wave lengths of light.

**APPARENT FIELD.** The apparent angular size of the field of view of an optical instrument, as seen through the instrument. See **FIELD OF VIEW**.

**AQUEOUS HUMOR.** The transparent liquid which is contained between the cornea and the crystalline lens of the eye (fig. 70).

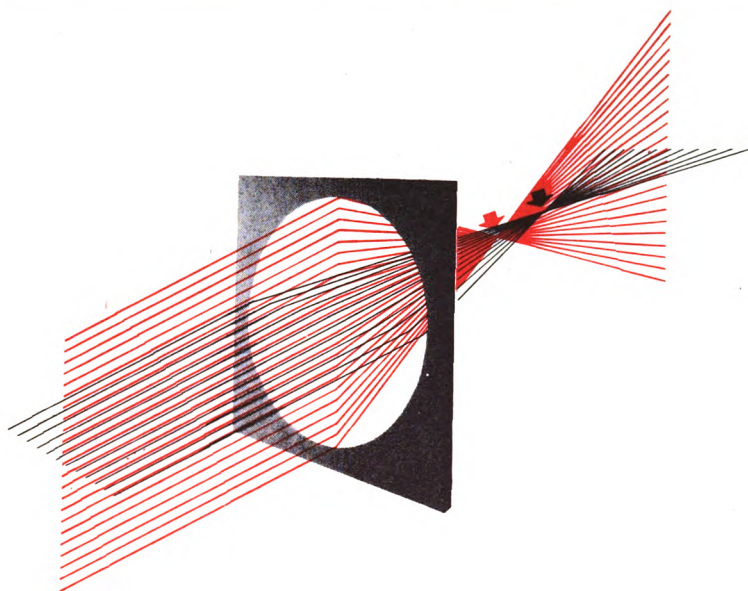
**ARC.** A part of the circumference of a circle.

**ASTHENOPIA.** Weakness or rapid fatigue resulting from use of the eyes; indicated by headache or pain in the eyes. Often referred to as weak sight, eyestrain, or eye-stretching.

**ASTIGMATISM.**

1. An aberration or defect of a lens which causes a point on the object to be imaged as a short line or pair of short lines. When two lines are formed, each is at a different distance from the lens and is at right angles to the other, and the lens has two points of principal focus (fig. 150). A sharp image cannot be secured at either focal point, and must be obtained at a point between the two focal points in a plane known as the *circle of least confusion*. This defect is caused by unsymmetrical curvature of the lens surfaces.

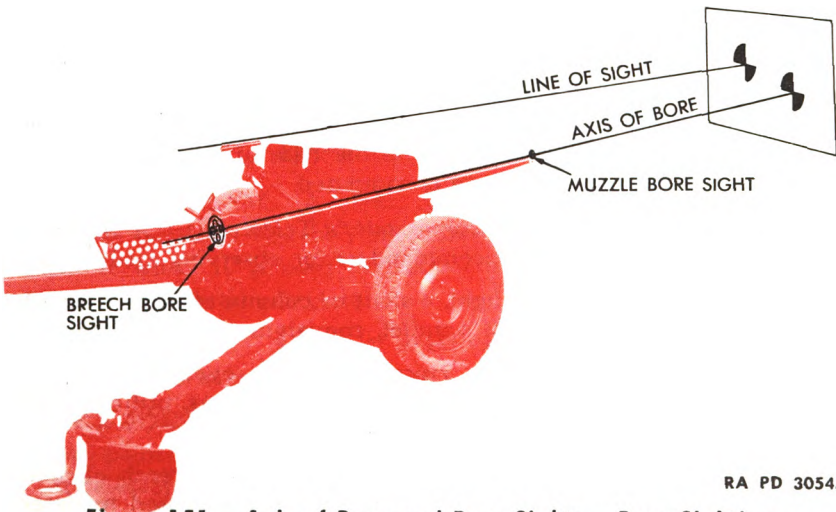
2. A defect of the human eye causing straight lines in a certain direction to appear blurred and distorted while lines in another direction may be well defined. This defect results when rays from a point at a certain angle are not brought to a single focal point on the image on the retina. It is caused by unsymmetrical surfaces of the cornea of the eye.



RA PD 30544

Figure 150 – Astigmatism of a Lens

**ASTIGMATIZER.** A cylindrical lens which may be rotated into the line of sight of a range finder to cause the effect of astigmatism, to stretch a ray of light from a single point to form a line.



RA PD 30545

Figure 151 – Axis of Bore and Bore Sights – Bore Sighting



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Glossary

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**AXIS** (plural, **AXES**). A straight line passing through a body and indicating its center. See **AXIS OF BORE**; **PRINCIPAL AXIS**; **OPTICAL AXIS**.

**AXIS OF BORE**. The center line or straight line through the center of the bore of a gun (fig. 151).

**AXIS OF LENS**. See **PRINCIPAL AXIS**.

**AZIMUTH**. An angle measured clockwise in a horizontal plane, from a known reference point—frequently one of the norths—**Magnetic**, **Grid**, or **True North**. (See **ANGLE OF AZIMUTH**, above). Also used as an adjective to indicate reference to movement in a horizontal plane, as, *azimuth mechanism* or *azimuth instrument*. To traverse the carriage of a weapon in azimuth means to rotate the weapon from side to side in a horizontal plane.

**AZIMUTH INSTRUMENT**. A telescopic instrument used for measuring horizontal angles.

**AZIMUTH MECHANISM**. Any mechanical means provided for turning an instrument in azimuth (in horizontal plane). It usually contains a worm and wormwheel to give accurate, smooth movement.

**BACKLASH**. A condition wherein a gear forming part of a gear train may be moved without moving the next succeeding or preceding gear. It is due to space between the teeth of the meshing gears.

**BALANCE**. See **ORTHOPHORIA**.

**BALSAM**. See **CANADA BALSAM**.

**BASE LENGTH**. In range finders, the actual optical length of the instrument. It is approximately equal to the distance between the centers of the end windows. It is the base of the range triangle by means of which the range is computed.

**BC TELESCOPE** (Battery Commander's Telescope). A binocular telescope used by battery commanders for observing artillery fire.

**BEAM**. With reference to light, a shaft or column of light; a bundle of rays. It may consist of parallel, converging, or diverging rays.

**BINOCULAR**. Pertaining to vision with both eyes; also, a term applied to instruments consisting of two telescopes, utilizing both eyes of the observer.

**BORE SIGHT**. A sighting device consisting of a breech element and a muzzle element which, inserted in a gun, is used to determine the axis of the bore and the alinement of other sighting

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*Glossary*

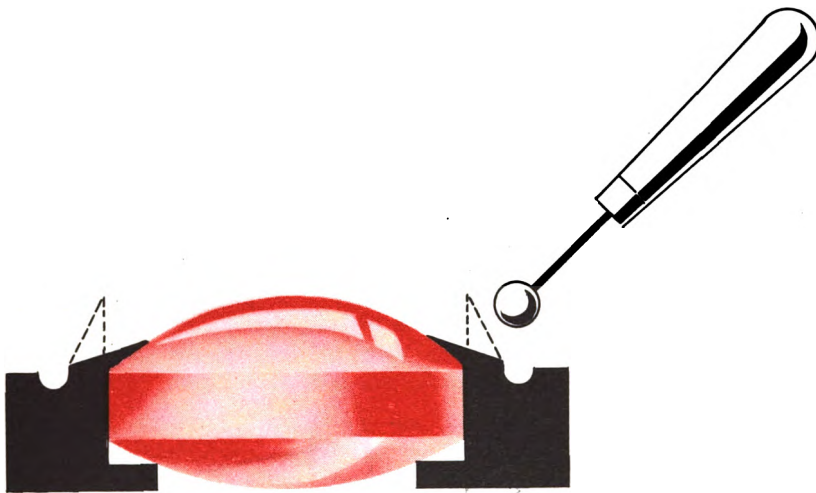
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equipment with the axis of the bore. A bore sight may consist of a metal disk with a peephole for the breech and a pair of cross lines for the muzzle (fig. 151).

**BORESIGHT.** To adjust the line of sight of the sighting instruments of a gun parallel to the axis of the bore (fig. 151).

**BRIGHTNESS OF IMAGE.** A term used to denote the amount of light transmitted by an optical system to give definition to the image seen by the observer.

**BURNISHING.** The process of turning a thin edge of metal over the beveled edge of a lens to hold it in place in its cell (fig. 152). This eliminates the use of a retaining ring. Burnished optics are difficult to replace and are usually procured as assemblies.



RA PD 30300

**Figure 152 — Burnishing**

**CANADA BALSAM.** A clear, colorless resin used in cementing optical elements together, particularly the components of a compound lens. It is used because it has approximately the same index of refraction as glass.

**CANDLEPOWER.** A unit of measure of the brightness or power of any light source.

**CASE I POINTING (or FIRING).** Direct pointing, laying, or fire; gun pointing in which direction and elevation are set with sight or telescope pointed at the target.

**CASE II POINTING (or FIRING).** Combined direct and indirect

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*Glossary*

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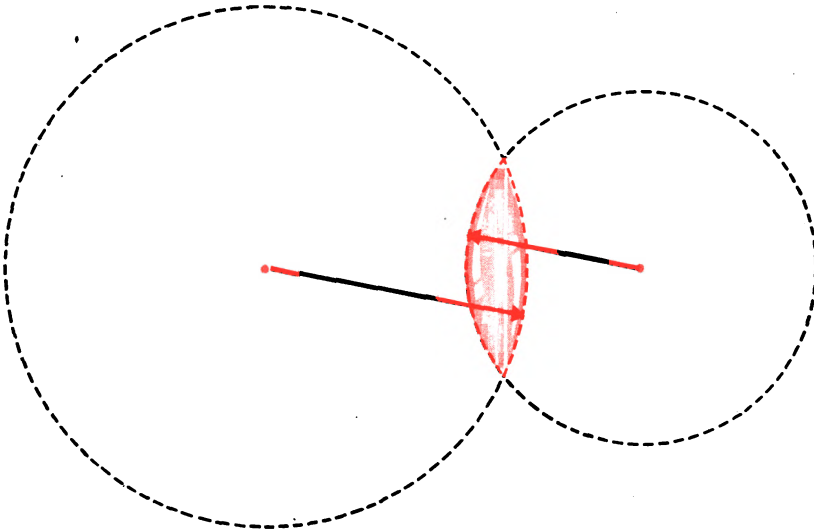
pointing, laying, or fire; gun pointing in which direction is set with a sight or telescope pointed at the target, and the elevation, with an elevation quadrant, range quadrant, or range disk.

**CASE III POINTING (or FIRING).** Indirect pointing, laying, or fire; gun pointing in which direction is set with an azimuth circle or with a sight or telescope pointed at an aiming point other than the target; the elevation is set with an elevation quadrant, range quadrant, or range disk.

**CATARACT.** A diseased condition of the human eye in which the cornea or crystalline lens becomes opaque, resulting in blindness.

**CELL.** A tubular mounting used to hold a lens in its proper position. The lens may be held in the cell by burnishing or by a retaining ring.

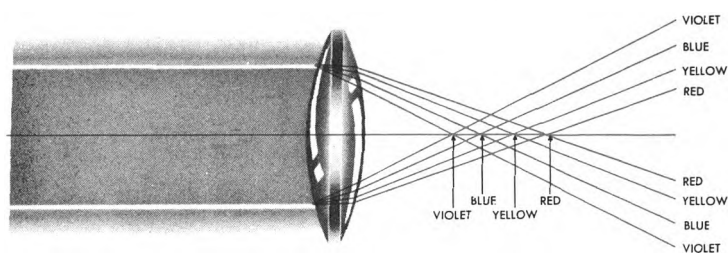
**CENTER OF CURVATURE.** The center of the sphere of which the surface of a lens or mirror forms a part. Each curved surface of a lens has a center of curvature (fig. 153). The curved surfaces may be convex or concave.



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**Figure 153 — Centers of Curvature**

**CHOROID.** The middle coat or tunic of the human eye. It is a deep purple layer made up of veins and blood vessels; it supplies nourishment to the eye tissues (fig. 70).

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**Figure 154 – Chromatic Aberration**

**CHROMATIC ABERRATION.** An aberration of a lens which causes different colors or wave lengths of light to be focused at different distances from the lens, resulting in colored fringes around the borders of objects seen through the lens (fig. 173).

**CILIARY BODY or MUSCLE.** A muscle in the eyeball which is capable of increasing or decreasing the curvature of the crystalline lens to increase or decrease the focal length of the lens system of the eye. Used in focusing and accommodation of the eyes (fig. 72).

**CIRCLE OF LEAST CONFUSION.** A focal plane between the two focal points of a lens affected by astigmatism where the most clearly defined image can be obtained.

**COATED OPTICS.** Optical elements which have been coated with a thin chemical film (magnesium fluoride) to reduce reflection and thereby increase light transmission.

**COINCIDENCE.** Agreeing as to position; corresponding. In a coincidence-type range finder, when the two half images of a distant object are alined, they are said to be "in coincidence."

**COINCIDENCE PRISM.** A compound prism, consisting of a system of small prisms cemented together, used in a coincidence range finder to bring the images from the two objectives to a single eyepiece for viewing.

**COINCIDENCE RANGE FINDER.** A self-contained distance measuring device operating on the principle of triangulation. Half images, observed from points of known distance, are matched to determine the range.

**COLLECTIVE LENS.** A convex or positive lens used in an optical system to collect the field rays and bend them to the next optical element. It prevents loss of light. Sometimes used to denote a convergent or convex lens.

**COLLIMATING TELESCOPE.** A telescope with an outer cylindrical surface that is concentric with its optical axis. It contains a

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Glossary

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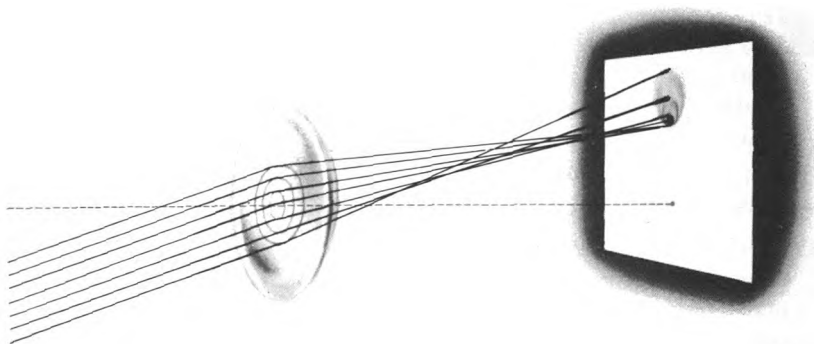
reticle, usually straight cross lines. It is used to aline the axis of the optical elements to the mechanical axis of the instrument (collimation), and to focus eyepieces, and to set diopter scales at infinity focus.

**COLLIMATION.** The process of alining the axis of the optical elements to the mechanical axis of an instrument.

**COLLIMATOR.** A sighting instrument occupying a position between the open sight and the telescopic instrument (fig. 113). It has an eyelens and reticle of cross line pattern.

**COLOR BLINDNESS.** An eye condition which prohibits the proper discrimination of colors. In the most common type, *dichromatism*, the individual does not see red or green but only yellow and blue, or certain combinations of them.

**COMA.** An aberration of a lens which causes oblique pencils of light from an object point to be imaged as a comet-shaped blur instead of a point. This aberration is caused by unequal refraction through the different parts of the lens (fig. 155).



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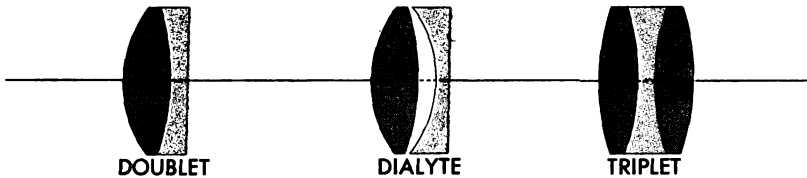
**Figure 155 — Coma**

**COMPASS NORTH (Magnetic North).** The direction indicated by the north-seeking end of the needle of a magnetic compass. This direction is different, usually, from either True North or Y-North, depending upon one's position upon the earth's surface.

**COMPENSATOR.** See MEASURING WEDGE.

**COMPOUND LENS.** A lens composed of two or more separate pieces of glass. These component pieces or elements may or may not be cemented together. A common form of compound lens is a two-element objective, one element being a converging lens of

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**Figure 156 – Compound Lenses**

crown glass and the other being a diverging lens of flint glass. The surfaces of the two elements are ground to eliminate aberrations which would be present in a single lens (fig. 156).

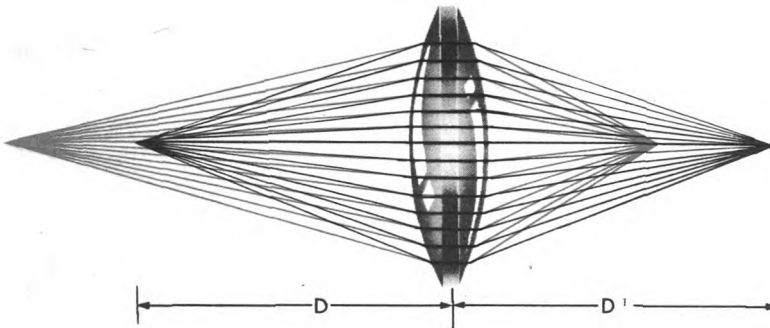
**CONCAVE.** Hollowed and rounded like the inside of a sphere.

**CONCAVE LENS.** See **DIVERGING LENS.**

**CONCAVO-CONVEX LENS.** A lens with one concave surface (toward the object) and one convex surface.

**CONCENTRIC.** Having the same center. Circles differing in radius but inscribed from a single center point.

**CONE.** One of the two types of light-sensitive elements or visual cells in the retina of the eye which permit sight. The cones are associated with daylight vision and give clear, sharp vision for the seeing of small details and the distinguishing of color. The other type of visual cell is termed the *rod* (fig. 73).



RA PD 30549

**Figure 157 – Conjugate Focal Points (Conjugate Foci)**

**CONJUGATE FOCAL POINTS (also CONJUGATE FOCI).** Those pairs of points on the principal axis of a mirror or lens so located that light emitted from either point will be focused at the other as shown in figure 157, where  $D$  and  $D'$  are the conjugate focal lengths. Related points in object and image located optically so

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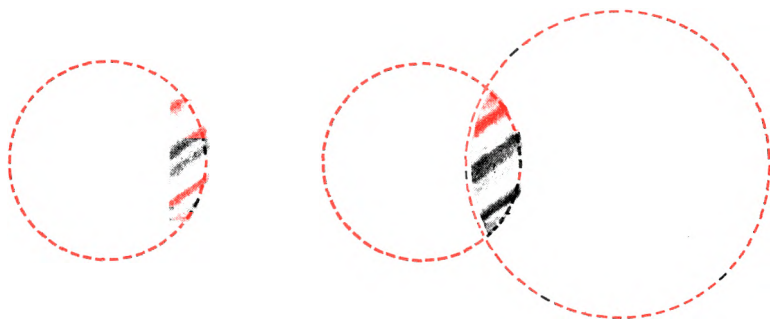
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that for every point on the object there is a corresponding point in the image.

**CONSTANT DEVIATION.** A certain amount of deviation given to the line of sight or optical axis of one of the internal telescopic systems of a range finder in order that the correction wedge may adjust the system by supplying a plus, neutral, or minus correction, as required.

**CONVERGE.** As applied to the eyes, to direct them so that the two lines of sight meet at a common focus and form an angle.

**CONVERGING LENS.** Also known as convergent lens, positive lens, convex lens, collective lens. A lens that will converge parallel light. One surface of a converging lens may be convexly spherical and the other plane plano-convex, both may be convex (double-convex) or one surface may be convex and the other concave (convexo-concave, meniscus converging). A converging lens is always thicker at the center than at the edge (fig. 158).



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**Figure 158 — Converging Lens**

**CONVEX.** Rounded and bulging outwardly as the outer surface of a sphere.

**CONVEX LENS.** See **CONVERGING LENS.**

**CONVEXO-CONCAVE LENS.** A lens with one convex and one concave surface; it is mounted with the convex surface toward the object.

**CORNEA.** The transparent, slightly bulging front surface of the eyeball through which all light enters (fig. 70).

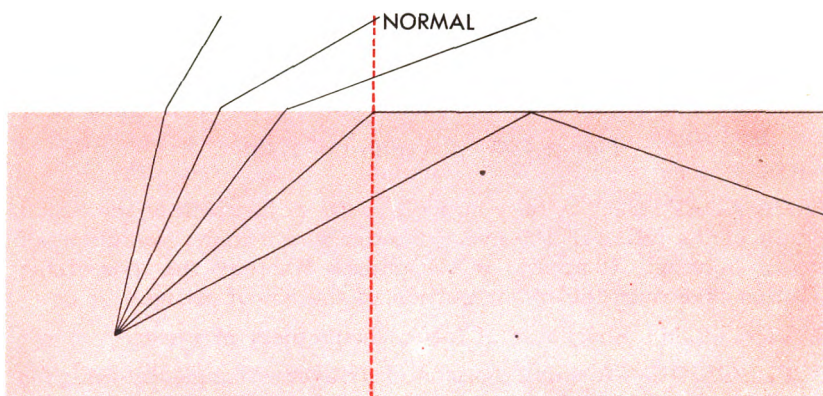
**CORRECTED LENS.** A compound lens, the various surfaces of which have been so designed with respect to each other that the lens is reasonably free from one or more aberrations.

**CORRECTION WEDGE.** In range finders and height finders, a rotating wedge-shaped element used to precisely divert the line



of sight to correct errors in the optical system caused by temperature variations.

**CORRECTION WINDOWS.** These are optical wedges of very small angles. They admit light, seal out dirt and moisture, and are so mounted that they may be rotated to compensate for the accumulated errors in the entire system. Two are used as end windows on some range finders.



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**Figure 159—Critical Angle**

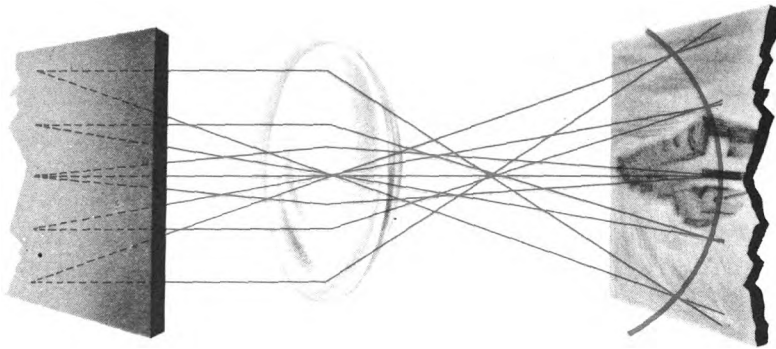
**CRITICAL ANGLE.** That angle at which light, about to pass from a medium of greater density into one of lesser density, is refracted along the surface of the denser medium (fig. 159). When this angle is exceeded, the light is reflected back into the denser medium. The critical angle varies with the *index of refraction* of the substance or medium.

**CROWN GLASS.** One of the two principal types of optical glass; the other type is *flint glass*. Crown glass is harder than flint glass, has a lower index of refraction, and lower dispersion. Both types are used in the making of *compound lenses*.

**CRYSTALLINE LENS.** The flexible inner lens of the eye which provides accommodation for sharply focusing near and distant objects (fig. 70).

**CURVATURE OF FIELD.** An aberration of a lens which causes an image to be focused in a curved plane instead of a flat one (fig. 160).

**CYLINDRICAL LENS.** A lens ground with a cylindrical surface instead of a spherical one. Lenses ground in this manner are used in spectacles to correct astigmatism, and in range finders to cause astigmatism by stretching points of light into lines of light.



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**Figure 160 — Curvature of Field**

**DARK-ADAPTED.** A term applied to the adjustment of the visual cells of the retina of the eye for better vision under conditions of poor lighting. It applies to the process whereby the *rods* of the retina take over the major portion of the act of seeing.

**DEFINITION.** Sharpness of focus; distinctness of image.

**DEFLECTION.** A small horizontal (traverse) angle by which a gun is aimed slightly away from its target to allow for factors such as wind and drift. See **DRIFT**.

**DEGREE.** A unit of measurement equal to 1/360 of a circle.

**DEPTH PERCEPTION.** The ability to see in depth or three dimensions. In addition to *stereoscopic vision*, light and shade, perspective, one object or part concealing another, and apparent size are factors which aid depth perception.

**DEVIATION.** Turning aside from a course; deflection; difference. In optics, the bending of light from its path. In gunfire, the distance from a point or center of impact to the center of a target.

**DIALYTE.** A type of compound lens in which the inner surfaces of the two elements are ground to different curvatures to correct for aberrations and the dissimilar faces cannot be cemented together (fig. 156).

**DIAPHRAGM.** A flanged or plain ring with a limited aperture placed in an optical system at any of several points to cut off marginal rays of light not essential to the field of view. Diaphragms are used as: *field stops*, to limit the field of view to that portion which is fully illuminated; *aperture stops*, to limit the aperture of light-gathering power of the instrument; and *anti-glare diaphragms*, to eliminate reflections from the sides of the tube and consequent glare in the field of view. Lens cells or the sides

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of the tube may act as diaphragms. The rays eliminated by diaphragms are those which would cause aberrations or glare by reflection inside the instrument.

**DICHROMATISM.** Form of *night blindness*.

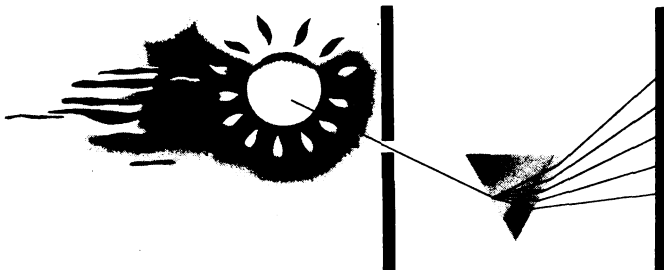
**DIFFUSION.** The scattering of light by reflection or transmission. Diffuse reflection results when light strikes an irregular surface such as a frosted window or the surface of a frosted or coated light bulb. When light is diffused, no definite image is formed.

**DIOPTER.** A unit of optical measurement which expresses the refractive power of a lens or prism. In a lens or lens system, it is equivalent to the reciprocal of the focal length in meters. The reciprocal is one of two quantities which when multiplied total one. For example, if a lens has a focal length of 25 centimeters, this figure converted into meters would equal  $\frac{1}{4}$  meter. Inasmuch as 4 times  $\frac{1}{4}$  meter equals one meter, such a lens would be said to have a power of 4 diopters. The lens with the shorter focal length has the greater power in diopters. See **PRISM DIOPTER**.

**DIOPTER MOVEMENT.** A term applied to adjustment of the eyepiece of an instrument to provide accommodation for eyesight variations of individual observers.

**DIOPTER SCALE.** A scale usually found on the focusing nut of the eyepiece of an optical instrument. It measures the change in refracting power of the eyepiece, in diopters, to introduce a correction to compensate for the nearsightedness or farsightedness of the individual observer. It permits presetting of the instrument if the observer knows his diopter correction.

**DIPLOPIA.** See **DOUBLE VISION**.



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Figure 161 — Dispersion

**DISCERNIBLE DIFFERENCE OF CONVERGENCE ANGLES.**

The differences in the angles of view from the two eyes to objects

or parts of objects. These differences, although small, permit persons with normal, two-eyed vision to distinguish which of two objects are farther away, making stereoscopic vision possible without resorting to the other factors which aid *depth perception*.

**DISPERSION.** In optics, the separation of a beam of so-called "White light" into its component colors, as in passing through a prism (fig. 161). See **SPECTRUM**.

**DISPERSIVE LENS.** See **DIVERGING LENS**.

**DISTORTION.** The aberration of a lens or lens system which causes objects to appear misshapen or deformed when seen through the lens or lens system. This defect is known as "barrel-shaped" distortion when the center of the field of view is enlarged with respect to the edges, and "pin-cushion" distortion when the edges are enlarged with respect to the center (fig. 162). Wavy lines are sometimes produced by improperly polished windows, prisms, and mirrors. When caused by a lens, it is due to varying magnification of different parts of the image.

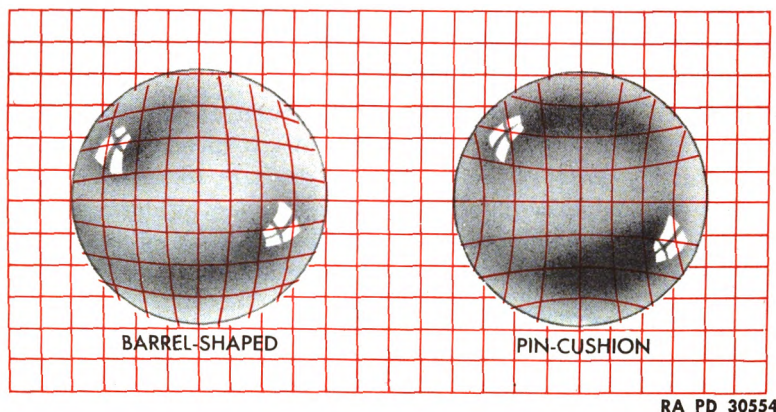


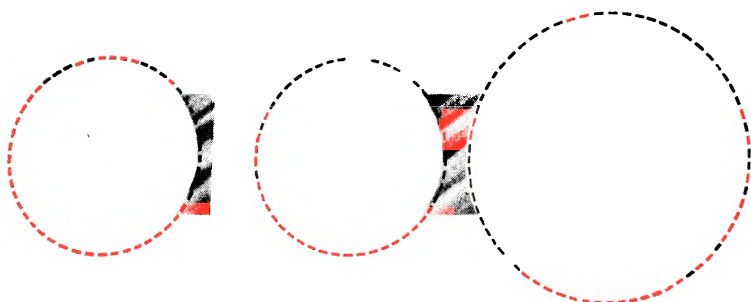
**Figure 162 — Distortion**

**DIVERGE.** As applied to the eyes, the action of the pupils being directed outwardly, or in not being brought to a common focus.

**DIVERGENT-MENISCUS LENS.** A lens with one convex surface and one concave surface, the concave surface being of the greater power (fig. 179). Spectacle lenses of this type are used to correct nearsightedness (myopia).

**DIVERGING LENS.** Also known as divergent lens, negative lens, concave lens, dispersive lens. A lens which causes parallel light rays to spread out. One surface of a diverging lens may be concavely spherical and the other plane (plano-concave), both may





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**Figure 163 — Diverging Lens**

be concave (double concave) or one surface may be concave and the other convex (concave-convex, divergent-meniscus). The diverging lens is always thicker at the edge than at the center (fig. 163).

**DOUBLE-CONCAVE LENS.** A lens with two concave surfaces (fig. 179).

**DOUBLE-CONVEX LENS.** A lens with two convex surfaces (fig. 179).

#### **DOUBLE VISION.**

1. A malfunction of a binocular instrument causing two images to be seen separately instead of being fused. It is caused by the optical axes of the two telescopes not being parallel. In minor cases, the eyes will adjust themselves to compensate for the error of the instrument until the images are superimposed and only one object is seen. This may cause eyestrain, eye fatigue, and headaches.

2. An eye disorder, known as diplopia, which results in double vision of a single object. It is usually caused by one eye failing to converge or diverge in unison with the other eye.

**DOUBLET.** A compound lens consisting of two elements with inner surfaces curved identically and cemented together (fig. 156).

**DOVE PRISM.** Also known as rotating prism. A form of prism designed by H. W. Dove. It is used to invert the image in one plane without deviating or displacing the axis. Used as the rotating prism in the conventional type of optical system of panoramic telescopes (fig. 90).

**DRIFT.** The amount by which a projectile will deviate from its proper path, due to rotation caused by the rifling in the bore of the gun (fig. 164).

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**Figure 164 — Drift**

**DYNAMETER.** An optical dynameter is a small telescope or magnifier equipped with a micrometer and used in the precise measurement of the exit pupil and eye distance of other optical instruments.

**ECCENTRIC MOUNTING.** A type of lens mounting consisting of eccentric rings which may be rotated to shift the axis of the lens to a prescribed position (fig. 110).

**EFFECTIVE APERTURE OR OBJECTIVE.** See **APERTURE**, above.

**ELBOW TELESCOPE.** A refracting optical instrument for viewing objects in which the line of sight is bent 90 degrees by means of a prism.

**ELECTROMAGNETIC SPECTRUM.** A chart or graph showing the relation of all known electromagnetic wave forms classified by wave length. The visible light spectrum occupies an extremely minute portion of the electromagnetic spectrum (fig. 4).

**ELEMENTARY LENS EQUATION.** A law giving the quantitative relation between the distance of the object, the image, and the principal focus of the lens.

**EMERGENT RAY.** In optics, the term applied to a ray of light leaving a dense medium as contrasted with the entering or *incident ray*.

**EMMETROPIA.** Normal refractive condition of the eyes. A normal eye is termed emmetropic.

**END PLAY.** Movement of a shaft along its axis. A type of lost motion common to worm and wormwheel assemblies. The error lies in looseness in the bearings at the ends of the shaft or in the ball cap and socket. The result is that the worm can be rotated a small amount without causing rotation of the wormwheel.

**ENTRANCE PUPIL.** The real image formed by all lenses or optical elements preceding the eyepiece; also used as a term to denote the aperture of the objective.

**EQUILIBRIUM, EQUIPOISE.** Muscular balance of the eyes.

**ERECT IMAGE.** The image produced by an optical system which appears as it is seen by the normal eye.

**ERECT TYPE.** The image produced by one type of coincidence range finder in which the image appears normal when in coincidence except for the presence of the *halving line*.

**ERECTING SYSTEM.** Lenses or prisms, the function of which are to erect the image, that is, to bring the image upright after it has been inverted by the objective. An erecting system may consist of a pair of lenses (fig. 165), each of which is called an erector, or of one or more prisms (figs. 141 and 143).

**ERECTOR.** One of the lenses of a lens erecting system (fig. 165).

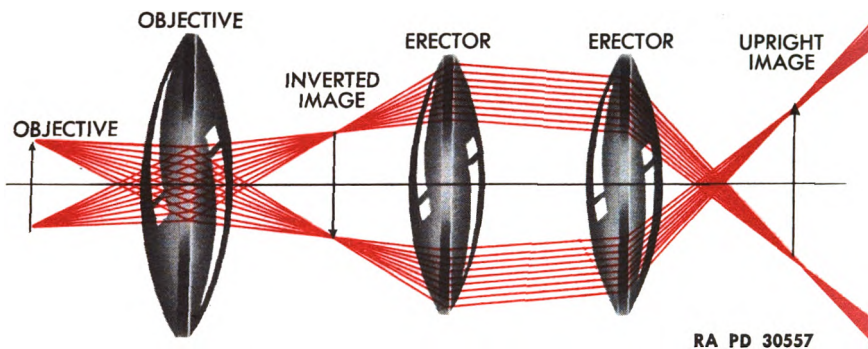


Figure 165 - Lens Erecting System

**ESOPHORIA.** A condition of the eyes in which the lines of sight tend to turn inwardly.

**ETCHING.** The marking of a surface by acid, acid fumes, or a tool. A process extensively used in the manufacture of reticles.

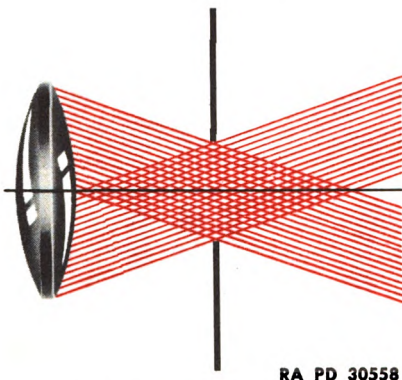


Figure 166 - Exit Pupil

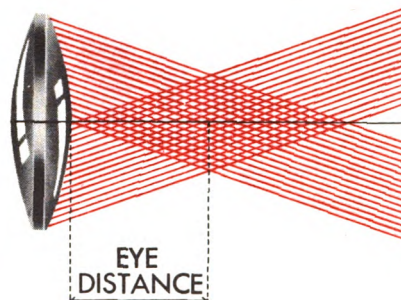


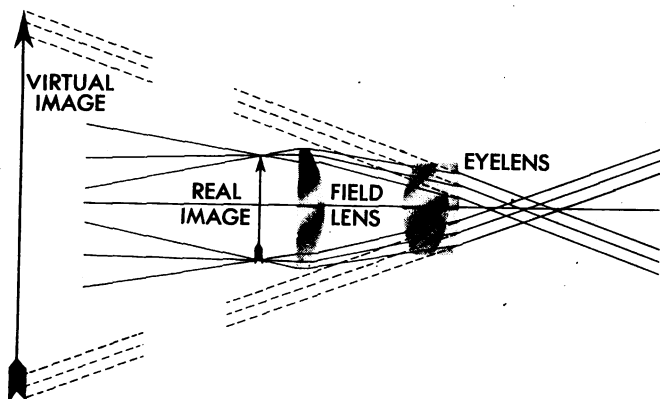
Figure 167 - Eye Distance



**EXIT PUPIL.** The small circle or disk of light which is seen by looking at the eyepiece of an instrument directed at an illuminated area or light source (fig. 166). Its diameter is equal to the entrance pupil divided by the magnification of the instrument.

**EXOPHORIA.** A condition of the eyes in which the lines of sight tend to turn outwardly.

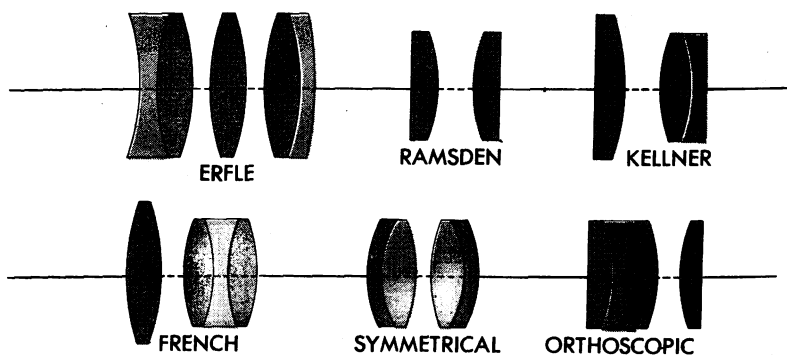
**EYE DISTANCE or EYE RELIEF.** The distance from the rear surface of the eyelens to the plane of the exit pupil (fig. 167). The center of rotation of the observer's eye should be situated in this plane. The center of rotation of the eye is about 6 mm behind the vertex of the cornea.



RA PD 30560

**Figure 168 — Eyelens and Field Lens of Eyepiece**

**EYE LENS.** The lens of an eyepiece which is nearest to the eye (fig. 168). See **EYEPIECE**. Various types of lenses are used for this purpose.



RA PD 30561

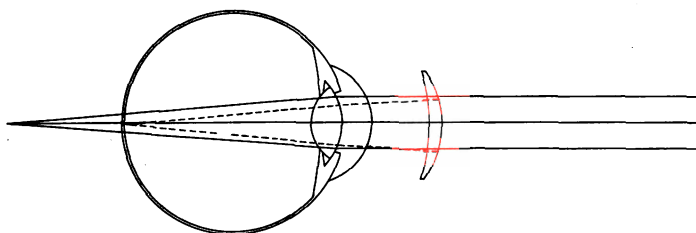
**Figure 169 — Types of Eyepieces**

**EYEPIECE.** An optical system used to form a virtual, enlarged image of the real image formed by the objective (fig. 169), and to adapt the light to the eye of the observer. The optical system of the eyepiece usually consists of two lenses, an eyelens and a collective or field lens, but the eyepiece may contain another lens.

**EYESHIELD or EYEGUARD.** A shield of rubber, plastic, or metal to protect the eyes of the observer from stray light and wind and to maintain proper eye distance.

**FAR POINT.** The farthest point of clear vision of the unaccommodated eye. For the normal eye, the far point is infinity.

**FARSIGHTEDNESS (Hypermetropia).** An eye defect in which the image tends to be focused beyond the retina with the result that the image is blurred and indistinct. It is caused by the refracting surface of the eye being too slightly curved, or by the eye being of insufficient depth. It is corrected by a converging lens (fig. 170).



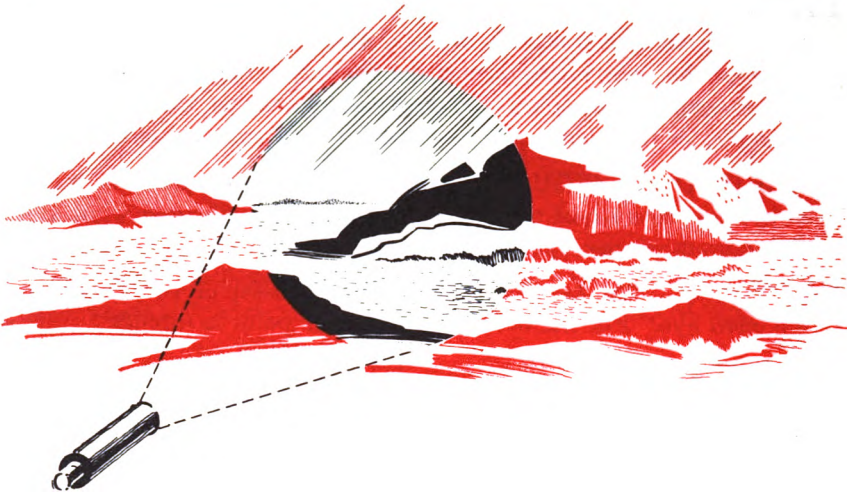
RA PD 30562

**Figure 170 — Farsightedness (Hypermetropia)**

**FIELD GLASS.** A type of *binocular*.

**FIELD LENS.** One of the lenses of an eyepiece. It is the lens which is nearest the image upon which the eyepiece is focused. It collects rays from the margin of the field and directs them into the eyelens, adding to the brightness of the image (fig. 168).

**FIELD OF VIEW.** The open or visible space commanded by the eye. It is the maximum angle of view that can be seen at one time. In an instrument, the *true field of view* is the actual angle of view of the instrument, the maximum angle subtended by any two objects which can be viewed simultaneously. The *apparent field of view* is the size of the field of view as it appears to the eye or the area in which the virtual image is formed; it is equal to the magnifying power of the instrument times the angle of the true field of view (fig. 171).



RA PD 30563

**Figure 171 — Field of View**

**FILTERS** or **RAY FILTERS**. Colored glass disks with plane, parallel surfaces placed in the path of light through the optical system of an instrument to reduce glare and light intensity. They are provided as separate elements, or as integral devices mounted so they may be placed in or out of position as desired (fig. 102).

**FINITE**. Having limits, as opposed to *infinite*, without limits.

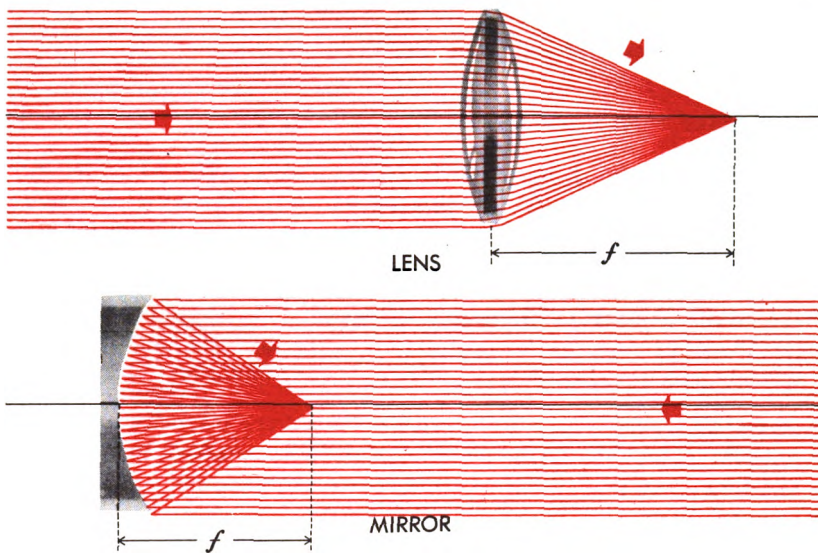
**FIRE CONTROL**. The determination and regulation of the direction of gunfire. More specifically, it refers to the observations and calculations necessary for determining the correct aiming of an artillery piece.

**FIXED FOCUS**. The term applied to instruments which are not provided with means for focusing. Such instruments, generally, have a wide range of accommodation which permits them to be used by the majority of observers.

**FLINT GLASS**. One of the two principal types of optical glass, the other being *crown glass*. Flint glass is softer than crown glass, has a higher index of refraction, and higher dispersion. See **COMPOUND LENS**, above.

**FLUORESCENCE**. Phenomenon whereby light of one wave length is absorbed by a material, and then reemitted as light of a different wave length. Fluorescent light sources require some exciting agent to cause them to become luminous. They cease to become luminous when the exciting agent is removed.

**FOCAL LENGTH**. The distance from the principal focus (focus of

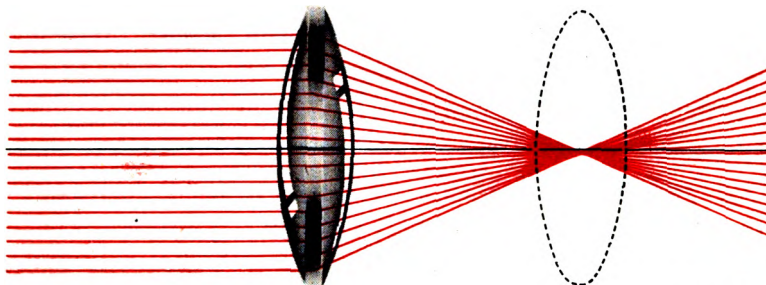


RA PD 30564

**Figure 172 – Principal Focal Lengths of Lens and Mirror**

parallel rays of light) to the surface of a mirror or the optical center of a lens (fig. 172).

**FOCAL PLANE.** A plane (through the focal point) perpendicular to the principal axis of a lens or mirror.



RA PD 30565

**Figure 173 – Focal Plane**

**FOCAL POINT.** The point to which rays of light converge or from which they diverge when they have been acted upon by a lens or mirror (fig. 172).

**FOCUS.**

1. To adjust the eyepiece of a telescope so that the image is clearly seen by the eye, or to adjust the lens of a camera so that a

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sharp, distinct image is seen on the ground glass.

2. The process of adjusting the distances between optical elements.

3. Same as *focal point*.

**FOCUSING NUT.** A threaded nut to which the eyepiece of a telescope is attached to permit the eyepiece to be moved in or out to accommodate the instrument to eyesight variations. It usually carries a *diopter scale* to permit presetting of the instrument (fig. 112).

**FOCUSING SLEEVE.** A knurled sleeve which is rotated to shift the positions of the erectors with relation to the objective and eyepiece to focus the instrument or to change its magnification.

**FOOT-CANDLES.** A unit of measurement of the intensity of illumination. A foot-candle is the amount of light received on a surface one foot away from a light source of one candlepower.

**FOVEA or FOVEA CENTRALIS** (yellow spot). A tiny area of cones in the center of the macula of the retina of the eye. It is the area of the eye responsible for the clearest vision.

**FREQUENCY.** In light or other wave motion, the number of crests of waves that pass a fixed point in a given unit of time, usually one second.

**FRONT SURFACE MIRROR.** An optical mirror on which the reflecting surface is applied to the front surface of the mirror instead of to the back.

**FUSE.** In stereoscopic vision, the action of seeing as one image the images seen by the two eyes.

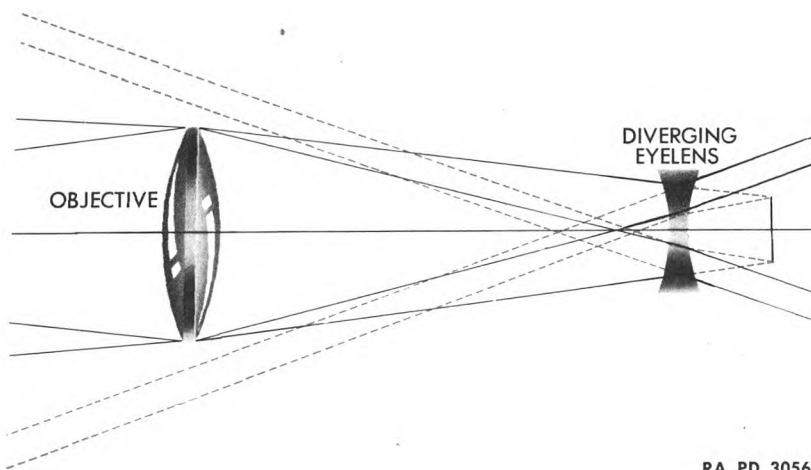
**FUSION.** The mental blending of the right and left eye images into a single, clear image by stereoscopic action.

**GEAR TRAIN.** Two or more gears meshed together so that rotation of one causes rotation of the others.

**GEOMETRICAL CENTER.** As applied to lenses, the physical center of the lens as determined by measurement; sometimes referred to as the mechanical center to distinguish it from the optical center.

**GHOST IMAGE.** A hazy second image caused by reflection sometimes seen in observing through a telescope.

**GIMBAL JOINT.** A mechanism which permits rotation around two perpendicular axes.



RA PD 30566

**Figure 174 — Optical System of Galilean Telescope**

**GRID DECLINATION.** The angle between True North and Y-North.

**GRID NORTH.** See Y-NORTH.

**GUNNER'S QUADRANT.** An instrument with a graduated arc, used in range adjustment. It measures the angle of elevation of the gun.

**HALVING LINE.** The line which divides the two half images in a coincidence type range finder. The two halves of the images produced by the two objectives of the instrument must be brought to a point where they match or coincide above and below the halving line.

**HARD COAT.** The term applied to the coating of magnesium fluoride on coated optics to differentiate between other and softer coatings which are less durable.

**HEIGHT FINDER.** An instrument used to find the height or altitude of aerial targets by means of optical triangulation. The instruments used employ the stereoscopic principle.

**HEIGHT OF IMAGE ADJUSTER.** A glass plate with plane surfaces which is tipped one way or the other in the line of sight in one of the internal telescopes of a range or height finder. It deviates the light upward or downward to adjust the image of one eyepiece to the same height as the image visible in the other eyepiece.

**HETEROPHORIA.** Any disturbance of the power, strength, or

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nervous system of the eye muscles which does not permit both eyes to function together in a normal way. It may occur in any of a number of different forms such as *esophoria* in which the lines of sight tend to turn inwardly, *exophoria* in which they tend to turn outwardly, and *hyperphoria* in which the line of sight of one eye tends to be above that of the other.

**HOMOGENEOUS.** Uniform throughout; composed of similar parts.

**HORIZONTAL TRAVEL.** Rotation of an instrument (or the line of sight of an optical instrument) in a horizontal plane; traverse.

**HYPERMETROPIA and HYPEROPIA.** See **FARSIGHTEDNESS**.

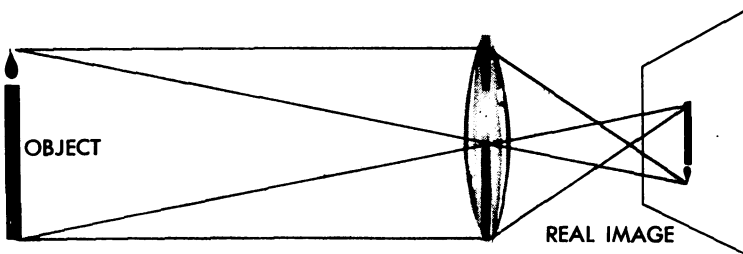
**HYPERPHORIA.** A condition of the eyes in which the line of sight of one eye tends to be above that of the other.

**HYPERPHORIC DISPLACEMENT.** Action of the eyes necessary to obtain fusion in observing through a stereoscopic or binocular instrument when the image seen by one eye is above that seen by the other eye.

**ICELAND SPAR.** A mineral that has the faculty of polarizing light.

**ILLUMINATED.** Lighted by another source than itself, as opposed to a luminous body, which is a light source.

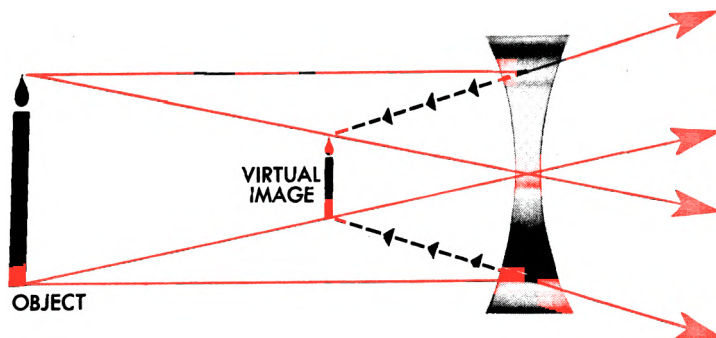
**IMAGE.** A reproduction or picture of an object produced by light rays. An image-forming optical element produces an image by collecting a beam of light diverging from an object point and transforming it into a beam which converges toward, or diverges from, another point. If the beam converges to a point, a real image is produced (fig. 175); if the beam diverges, a virtual image is produced at its apparent source (fig. 176). A real image can be thrown upon a screen (fig. 175); a virtual image exists only in the mind of the observer.



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**Figure 175 — Real Image Produced by Converging Lens**





RA PD 30568

**Figure 176 – Virtual Image Produced by Diverging Lens**

**IMAGE PLANE.** The plane in which the image lies or is formed.

It is perpendicular to the axis of the lens and is at the focal point.

A real image formed by a converging lens would be visible upon a screen placed in this plane (fig. 175).

**IMBALANCE.** See **HETEROPHORIA**.

**INCANDESCENCE.** The state of a body in which its temperature is so high that it gives off light. Example: the sun, or the filament of an electric lamp.

**INCIDENCE.** The act of falling upon or affecting, as light upon a surface.

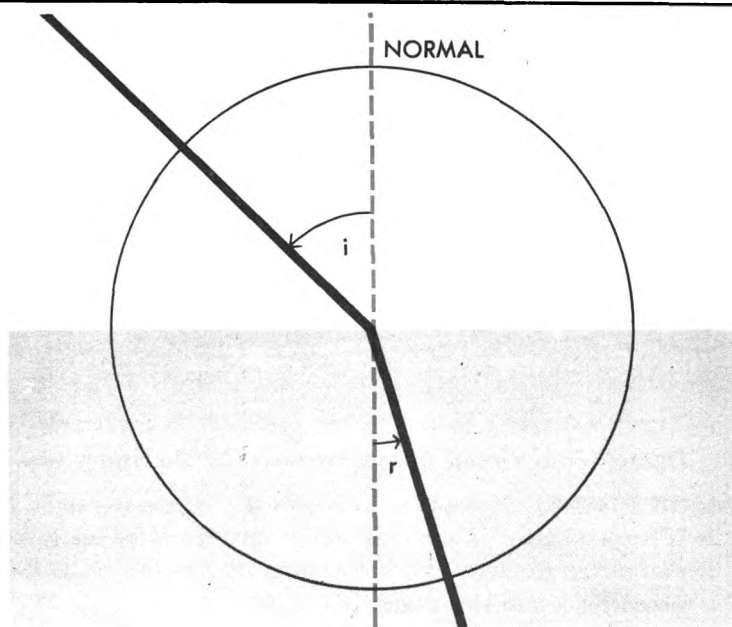
**INCIDENT RAY.** A ray of light which falls upon or strikes the surface of an object such as a lens or mirror. It is said to be incident to the surface (fig. 147).

**INDEX** (plural, **INDICES**).

1. An arrow or mark against which a calibration, graduation, or scale is set to indicate the extent to which a mechanism is adjusted; something that points out.
2. The ratio of one dimension or quality to another.

**INDEX OF REFRACTION.** A number applied to a transparent substance which denotes how much faster light will travel in vacuum than through that particular substance. It determines the relation between the angle of incidence ( $i$ ) and the angle of refraction ( $r$ ) when light passes from one medium to another (fig. 177). The index between two media is called the *relative index*, while the index when the first medium is a vacuum is called the *absolute index* of the second medium. The relative index is the ratio of the sine of the angle of incidence to the sine of the angle of refraction, or the speed of light in the second medium. This relation is

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**Figure 177 — Index of Refraction**

expressed as:

$$n = \frac{\sin i}{\sin r} = \frac{\text{Speed of light in air}}{\text{Speed of light in other medium}} \quad (\text{Snell's law})$$

where  $n$  equals the relative index of refraction,  $i$  equals the angle of incidence, and  $r$  equals the angle of refraction. **NOTE:** *The index of refraction expressed in tables is the absolute index, that is, vacuum to substance at a certain temperature, with light of a certain wave length. Examples: vacuum, 1.000; air, 1.000292; water, 1.333; ordinary crown glass, 1.516. Since the index of air is very close to that of vacuum, the two are often used interchangeably as being practically the same.*

**INFINITE.** Without limit, as opposed to *finite*, meaning with limits.

**INFINITY.** The extreme point of distance. In optics, the term is used to denote a distance sufficiently great so that light rays coming from that distance are practically parallel to one another. Infinity is indicated by the symbol  $\infty$  or  $*$ .

**INTERPUPILLARY.** Between the pupils of the eyes.

**INTERPUPILLARY ADJUSTMENT.** The adjustment of the distance between the eyepieces of a binocular instrument to correspond with the distance between the pupils of the eyes of an individual.

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**INTERPUPILLARY DISTANCE.** The distance between the centers of the pupils of the eyes. It is generally stated in millimeters. It varies with the individual.

**INVERT TYPE.** The type of image observed in certain coincidence range finders. When in coincidence, the upper half image appears to be the mirrored reflection of the lower half image.

**INVERTED.** Turned over; upside-down. Usually refers to the effect of a prism or lens upon the image. Inversion is the effect of turning upside-down.

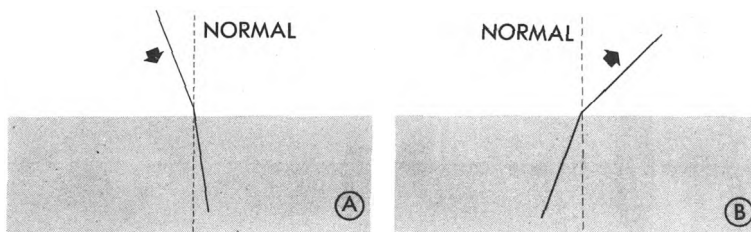
**IRIS.** The colored part of the eye about the pupil. Depending upon the intensity of light, the iris causes the pupil to dilate or contract.

**JACK SCREW.** A screw threaded through one part and pressing against another.

**LATENT CONVERGENCE.** See ESOPHORIA.

**LATENT DIVERGENCE.** See EXOPHORIA.

**LAW OF REFLECTION.** The angle of reflection is equal to the angle of incidence; the incident ray, reflected ray, and normal, all lie in the same plane (fig. 147).



RA PD 30570

**Figure 178 — Law of Refraction**

**LAW OF REFRACTION.** When light is passing from a lighter medium to a denser medium, its path is deviated *toward* the normal (fig. 178A); when passing into a less dense medium, its path is deviated *away from* the normal (B in fig. 178). The amount of deviation is determined by means of the equation for the index of refraction for the two media involved (see INDEX OF REFRACTION).

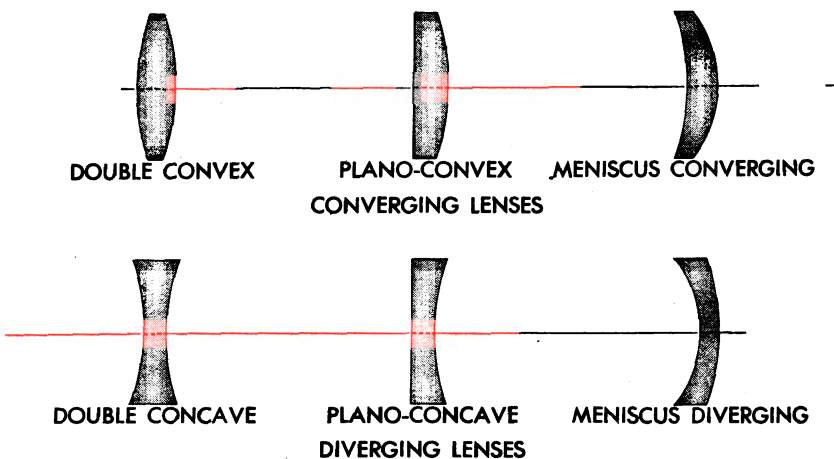
**LAW OF RELATIVE SIZE OF OBJECT AND IMAGE.** The size of the image is in direct proportion to the size of the object as the relative distance from the lens (mirror) to the object and image.

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**LAW OF REVERSIBILITY.** If the direction of light be reversed, it will travel in the opposite direction over the same path despite the number of times it is reflected or refracted.

**LEAST CIRCLE OF ABERRATIONS.** The circular portion about the axis of a lens where aberrations are the least apparent.

**LENS** (plural, **LENSES**). A transparent object, usually a piece of optical glass, having two polished surfaces of which at least one is curved, usually with a spherical curvature. It is shaped so that rays of light, on passing through it, are made to converge or diverge. The fact that lenses either converge or diverge rays provides one means of classification; the type of curvature provides another (fig. 179); the corrections made in the lens provides still another. The term lens may be employed to mean a compound lens which can consist of two or more elements. See **ACHROMATIC LENS**; **ANASTIGMAT**; **APLANTIC LENS**; **APOCHROMATIC LENS**; **ASTIGMATIZER**; **COLLECTIVE LENS**; **COMPOUND LENS**; **CONCAVO-CONVEX LENS**; **CONVERGING LENS**; **CONVEXO-CONCAVE LENS**; **CORRECTED LENS**; **CYLINDRICAL LENS**; **DIALYTE**; **DIVERGING LENS**; **DIVERGENT-MENISCUS LENS**; **DOUBLE-CONCAVE LENS**; **DOUBLE-CONVEX LENS**; **DOUBLET**; **ERECTOR**; **EYELENS**; **FIELD LENS**; **MENISCUS-CONVERGENT LENS**; **MINUS LENS**; **OBJECTIVE**; **ORTHOSCOPIC LENS**; **PLANO-CONCAVE LENS**; **PLANO-CONVEX LENS**; **PLUS LENS**; **TRIPLET**.



RA PD 30571

**Figure 179 – Types of Simple Lenses**

**LENS EQUATION, ELEMENTARY.** The law of equation giving the relation between the distance of the object ( $D_o$ ), the distance of the image ( $D_i$ ), and the principal focus ( $F$ ). These values

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are presented as:

$$\frac{1}{D_o} \text{ plus } \frac{1}{D_i} \text{ equals } \frac{1}{F}$$

**LENS SYSTEM.** Two or more lenses arranged to work in conjunction with one another (fig. 186). When in proper alinement, the principal axes will be coincident and the system can be referred to as a "centered lens system."

**LENSES OF THE EYE.** The refractive elements of the eye. See *cornea* and *crystalline lens*.

**LIGHT-ADAPTED.** A term applied to the adjustment of the visual cells of the retina of the eye for the clearest and most distinct sight under good lighting conditions. It applies to the process whereby the cones of the retina take over the major portion of the act of seeing.

**LIGHT RAY.** The term applied to the radii of waves of light to indicate the direction of travel of the light. Light rays are indicated by arrows and lines.

**LIMITING ANGLE OF RESOLUTION.** The angle subtended by two points which are just far enough apart to permit them to be distinguished as separate points. It is commonly used as a measure of *resolving power*.

**LIMITS OF ACCOMMODATION.** The distances of the nearest and farthest points which can be focused clearly by the eyes of an individual. Usually varies from 4 or 5 inches to infinity. See **ACCOMMODATION**.

**LINE OF ELEVATION.** In artillery, the line of the axis of the bore of a gun when it is in firing position.

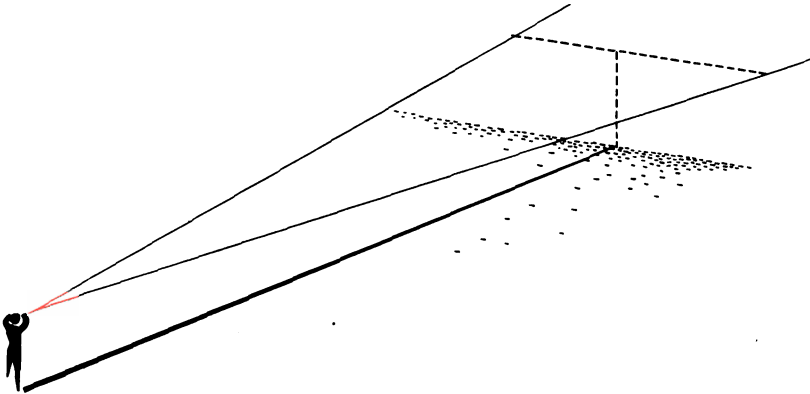
**LINE OF SIGHT.** Line of vision; optical axis of a telescope or other observation instrument. Straight line connecting the observer with the aiming point; the line along which the sights are set (fig. 151).

**LINE OF SITE.** A straight line extending from a gun or a position-finding instrument to a point, especially a target. Usually called line of position.

**LINEAR FIELD.** The actual width of the field of view at any distance (fig. 180).

**LOST MOTION.** Motion of a mechanical part which is not transmitted to connected or related parts. It is the cumulative result of *backlash* and *end play*.

**LUMINESCENCE.** Giving off of light at a temperature below that of incandescence. The radiating of "cold" light as seen from fireflies or luminous paint.



RA PD 30572

**Figure 180 — Linear Field**

**MACULA.** A small area of the retina of the eye which is highly sensitive to light and which is the zone of the clearest and most distinct vision except for a much smaller area at its center known as the *fovea* or *fovea centralia*. These areas are composed almost wholly of cones (fig. 70).

**MAGNETIC AZIMUTH.** Azimuth measured from Magnetic North.

**MAGNETIC DECLINATION.** The angle between True North and Magnetic North.

**MAGNETIC-GRID DECLINATION.** The angle between Magnetic North and Grid North.

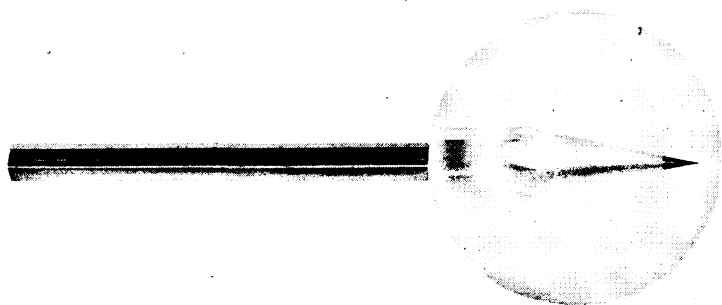
**MAGNETIC NEEDLE.** A magnetized needle used in a compass. When freely suspended, it will assume a position parallel to the earth's magnetic lines of force which connect the magnetic poles.

**MAGNETIC NORTH.** The direction of the earth's north magnetic pole as indicated by the north-seeking end of a magnetic needle.

**MAGNIFICATION.** The increase in the apparent size of an object produced by an optical element or instrument.

**MAGNIFYING POWER.** The ability of a lens, mirror, or optical system to make an object appear larger (fig. 200). If an optical element or optical system makes an object appear twice as high and twice as wide, the element or system is said to have a magnification of 2-power. The power of an optical instrument is the entrance pupil divided by the exit pupil, the focal length of the objective divided by the focal length of the eyepiece, or the apparent field of view divided by the true field of view.

**MARGINAL RAYS.** Rays of light near the edge of the field of a lens.



RA PD 30302

**Figure 181 — Magnifying Power**

**MEASURING WEDGE.** An optical element employed in a range or height finder to deviate light entering the variable angle end of the instrument. One type consists of a single, perpendicular wedge which is moved in alinement with the path of light to increase or decrease the amount of deviation. The other type consists of one or two pairs of circular wedges, each pair being capable of rotating equally or simultaneously in opposite directions about the axis of the path of light to produce variable deviation. The wedges of both types are compound elements corrected for color (fig. 96).

**MEDIUM** (plural, **MEDIA**). Any substance or space through which light can travel.

**MENISCUS-CONVERGENT LENS.** A lens, the surfaces of which are curved in the same direction; one surface is convex, the other is concave. The convex surface has the greater curvature or power (fig. 179).

**MICROMETER.** A mechanism for measuring small angles or dimensions. On optical instruments, it is the "fine" scale.

**MICROMETER SCALE.** An auxiliary scale used to read small angles or values.

**MICROMICRON.** A unit of measure equalling one-millionth part of a micron or one-billionth part of a millimeter.

**MICROMILLIMETER, or MILLIMICRON.** Terms variously applied to units of measure equal to one-millionth part of a millimeter or one-thousandth part of a micron.

**MICRON.** A unit of measure equalling one-thousandth part of a millimeter.

**MIL** (Artillery Mil). A unit of angular measurement used in military calculations. It is  $\frac{1}{6400}$ th of a complete circle, or very nearly the angle between two lines which will enclose a distance of one yard at a range of 1000 yards or two yards at a range of 2000 yards (fig. 182). 17.78 mils is approximately equal to 1 degree. **NOTE:** *The Navy mil and the French infantry mil are*



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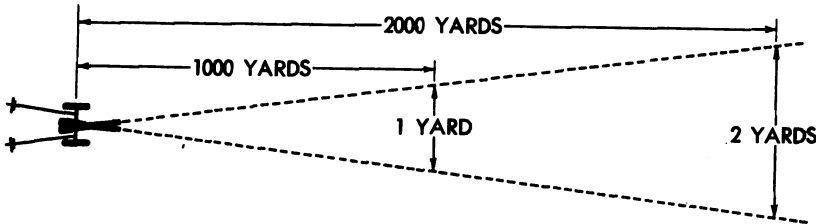


Figure 182 — Artillery Mil

RA PD 30303

*exactly one yard at a range of 1000 yards. There are 6283.1853 Navy or French infantry mils in a complete circle.*

**MINUS LENS.** A diverging lens. A lens with negative focal length (focal point toward the object).

**MINUTE.** A unit of measurement of part of a circle equal to one-sixtieth of a degree.

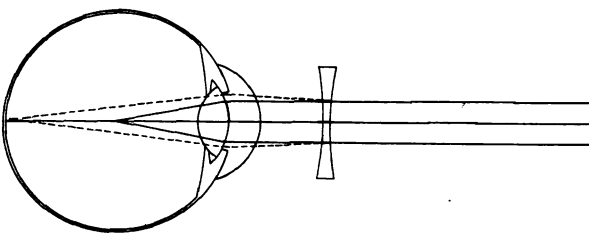
**MIRROR.** A smooth, highly polished surface for reflecting light. It may be plane or curved. Usually a thin coating of silver or aluminum on glass constitutes the actual reflecting surface. When this surface is applied to the front face of the glass, the mirror is termed a front surface mirror.

**MONOCHROMATIC.** Composed of one color.

**MONOCULAR.** Pertaining to vision with one eye. A term applied to optical instruments requiring the use of only one eye.

**MOUNT.** A device for attaching or supporting an optical instrument. It may or may not be provided with means for elevating and traversing the instrument, calibrations to indicate degree of movement, and means and gages for leveling. This term is applied also to means of securing an optical element in an instrument.

**MYOPIA.** An eye defect which does not permit distant objects to be seen clearly. It is the result of eyes that do not conform to standard measurements, having too much optical depth or too



RA PD 30573

Figure 183 — Nearsightedness (Myopia)

great curvature of surfaces. The image tends to be focused before it reaches the retina, and is indistinct. It is corrected by a diverging lens (fig. 183).

**NEAR POINT.** Closest point of clear vision with the eye.

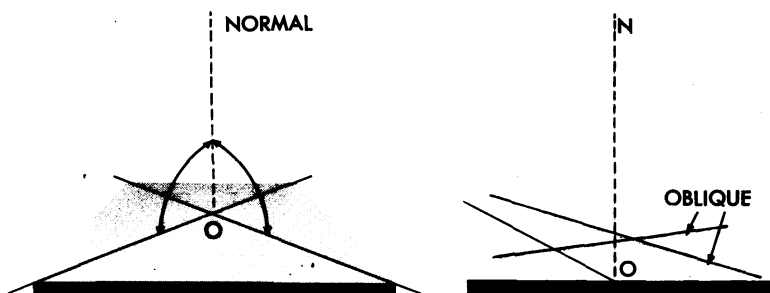
**NEARSIGHTEDNESS.** See **MYOPIA**.

**NEGATIVE LENS.** See **DIVERGING LENS**.

**NEWTON'S RINGS.** A series of concentric colored or bright and dark circles seen when positive and negative surfaces of nearly the same curvature are pressed together. It is caused by interference of light rays. It is used to test lenses. The more nearly the surfaces are matched, the greater the distance between the rings and the larger the circles (fig. 68).

**NIGHT BLINDNESS.** A condition of the eyes (and possibly the health) of a person which does not permit him to see as well at night or with poor illumination as the average person.

**NORMAL.** Sometimes called the *perpendicular*. An imaginary line forming right angles with a surface or other lines. It is used as a basis for determining angles of incidence, reflection, and refraction. In figure 184, the normal is perpendicular, or at right angles to all lines lying in the plane and passing through point O.



RA PD 30574

**Figure 184 — Normal and Oblique**

**OBJECT.** The principal thing imaged by the optical system. It may be part of a large object, an entire object plus its immediate surroundings, or a number of objects. It is a general term used for the sake of convenience.

**OBJECT DISTANCE.** The distance of an object from the eyes or from an optical system.

**OBJECTIVE.** The lens in an optical system which receives light from the field of view and forms the first image. It is the lens farthest from the eye and nearest the object viewed.

**OBJECTIVE CAP.** A protective device, usually made of leather, which is placed over the objective end of the instrument when the instrument is not in use (fig. 111).

**OBJECTIVE PRISM.** A right-angle prism employed in some types of instruments to bend light 90 degrees before it enters the objective (fig. 99).

**OBLIQUE.** Slanting; neither at right angles nor parallel. The solid red lines in figure 184 are oblique.

**OCULAR.**

1. A term sometimes applied to the *eyepiece*.
2. Pertaining to the eyes or eyesight.

**OCULAR PRISM.** The prisms employed in a range finder to bend the lines of sight through the instruments into the eyepieces.

**OFF-CARRIAGE INSTRUMENTS.** Those instruments used in artillery which are not mounted on the carriage of the weapon, such as the *aiming circle*, *BC telescope*, and *range finder*.

**OLDSIGHTEDNESS.** See **PRESBYOPIA**.

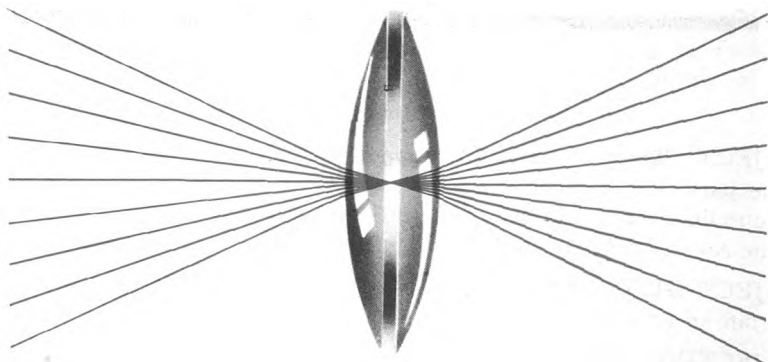
**ON-CARRIAGE INSTRUMENTS.** Those instruments used in artillery which are mounted directly on the carriage of the weapon, such as *panoramic* and *elbow telescopes* and *telescope mounts*.

**OPHTHALMIC.** Pertaining to the human eye.

**OPTICAL.** Pertaining to vision and the phenomena of light.

**OPTICAL AXIS.** The line formed by the coinciding principal axes of a series of optical elements comprising an optical system; in other words, an imaginary line passing through the optical center of the system.

**OPTICAL CENTER.** The point of a lens through which the rays



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Figure 185 — Optical Center of Lens

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pass and emerge parallel to their path of incidence (fig. 185). It is the thickest part of a converging (convex) lens and the thinnest part of a diverging (concave) lens.

**OPTICAL CHARACTERISTICS.** Those properties of an optical system which it possesses by reason of its optical nature, such as *field of view*, *magnification*, *brightness of image*.

**OPTICAL ELEMENT.** A part of an optical instrument which acts upon the light passing through the instrument, such as a *lens*, *prism*, or *mirror*.

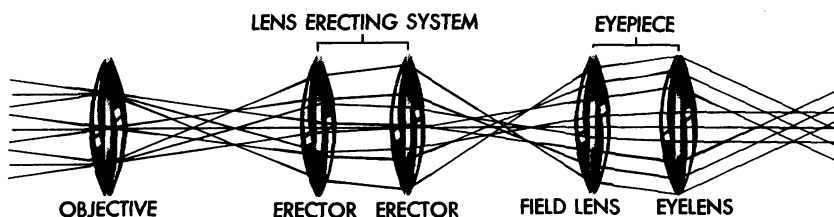
**OPTICAL GLASS.** Glass carefully manufactured to obtain purity, transparency, homogeneity, and correct optical properties. See

CROWN GLASS, FLINT GLASS.

**OPTICAL PROPERTIES.** In optical glass, those properties which pertain to the effect of the glass upon light, such as *index of refraction*, *dispersion*, *homogeneity*, and freedom from defects.

**OPTICAL SURFACE.** A reflecting or refracting surface.

**OPTICAL SYSTEM.** A number of lenses, or lenses and prisms, so arranged as to refract, or refract and reflect light, to perform some definite optical function (fig. 186).



RA PD 30576

**Figure 186 — Optical System of Erecting Telescope**

**OPTICS.** That branch of physical science which is concerned with the nature and properties of light and vision.

**ORBIT.** The socket of the human eye.

**ORIENT.** In fire control, to find the proper bearing; to fix the position of, with reference to a predetermined point.

**ORIENTATION.** Determination of the horizontal and vertical location of points and the establishment of orienting lines; adjustment of the azimuth circle of a weapon or instrument to read azimuths.

**ORTHOPHORIA.** A term used with reference to the eyes indicating that the eyes are equally and properly controlled by eye muscles

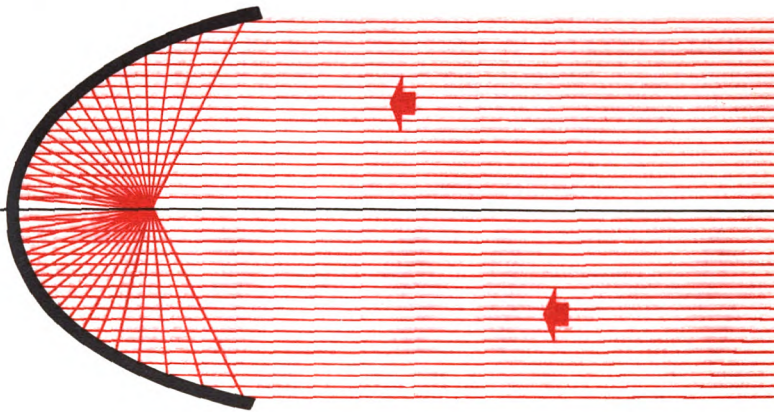
with the result that, with the eyes at rest, they focus upon a distant object.

**ORTHOSCOPIC EYEPIECE.** An eyepiece which has been corrected for distortion; particularly that type of eyepiece having a triple element cemented field lens and a meniscus eyelens. See **EYEPIECE**.

**ORTHOSCOPIC LENS.** A lens which has been corrected for distortion.

**PANORAMIC TELESCOPE.** A telescope so designed that the image remains erect and the position of the eyepiece is unchanged as the line of sight is pointed in any horizontal direction.

**PARABOLIC MIRROR.** A concave mirror which has the form of a special geometrical surface, a paraboloid of revolution. All light rays emanating from a source located at the focal point of the paraboloid are reflected as parallel rays. Most searchlights are of this design (fig. 187).

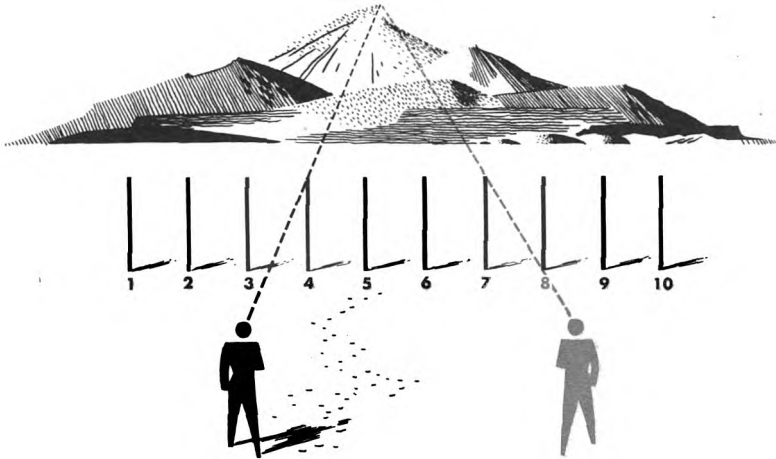


RA PD 30577

**Figure 187 — Parabolic Mirror**

**PARALLACTIC ANGLE.** In range finding, the angle at the target subtended by the base length. The base line of the range finder forms the base of a triangle and its apex is the target. Corresponds to the *angle of convergence* in stereoscopic vision.

**PARALLAX.** Any apparent displacement of an object due to the observer's change of position (fig. 188). Optically, parallax in a telescope with a reticle is any apparent movement of the reticle in relation to distant objects in the field of view caused by movement of the head of the observer. This condition exists when the image in the telescope lies in one focal plane and the reticle lies in another.



RA PD 30578

**Figure 188 — Demonstration of Parallax**

**PARAXIAL RAY.** Any ray parallel to the axial ray in a pencil of light.

**PATINA.** A film.

**PENCIL OF LIGHT.** A group of light rays coming from a point source, or converging toward a point. A pinhole opening produces a pencil of rays.

**PENTA PRISM.** A five-sided prism used to bend light through a constant angle, usually 90 degrees, without producing inversion (fig. 91).

**PERCENT STEREOPSIS.** A unit of measurement of the keenness of stereoscopic vision.

**PERIPHERAL.** Near the boundary or edge of the field of an optical system; the outer fringe.

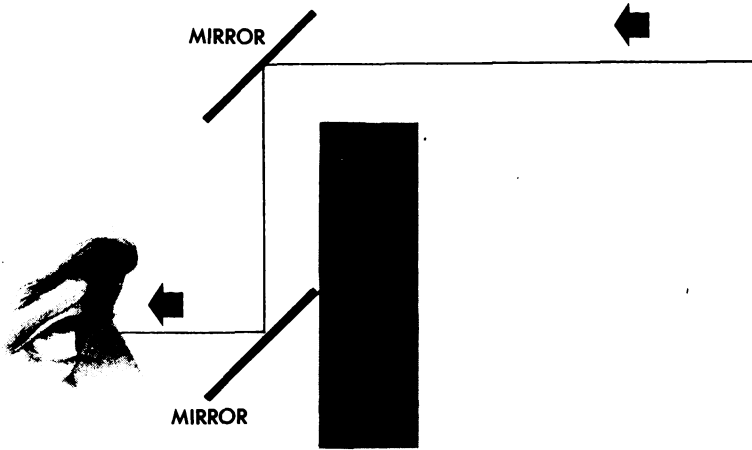
**PERISCOPE.** An optical instrument designed to displace the line of sight in a vertical direction. Used to permit observation over the top of a barricade or out of a tank (fig. 189).

**PERSPECTIVE.** Appearance in terms of distance. Example, railroad tracks which appear to converge as they are seen receding in the distance.

**PHOSPHORESCENCE.** The glowing or giving off of light without sensible heat; the property to shine in the dark after exposure to light; emission of light by chemical reaction, as in fireflies.

**PLANE.** A surface which has no curvature; a perfectly flat surface.

## Glossary



RA PD 30579

**Figure 189 — Principle of the Periscope**

**PLANO-CONCAVE LENS.** A lens with the front surface plane; the other concave.

**PLANO-CONVEX LENS.** A lens with the front surface plane; the other convex.

**PLUMB LINE.** A vertical line. When used as a target for adjusting instruments, it is a weight (plumb bob) hanging on a string.

**PLUS LENS.** A converging (convex) lens.

**POINT OF FIXATION.** The center of focus; an object on which the observer's eye attention is concentrated.

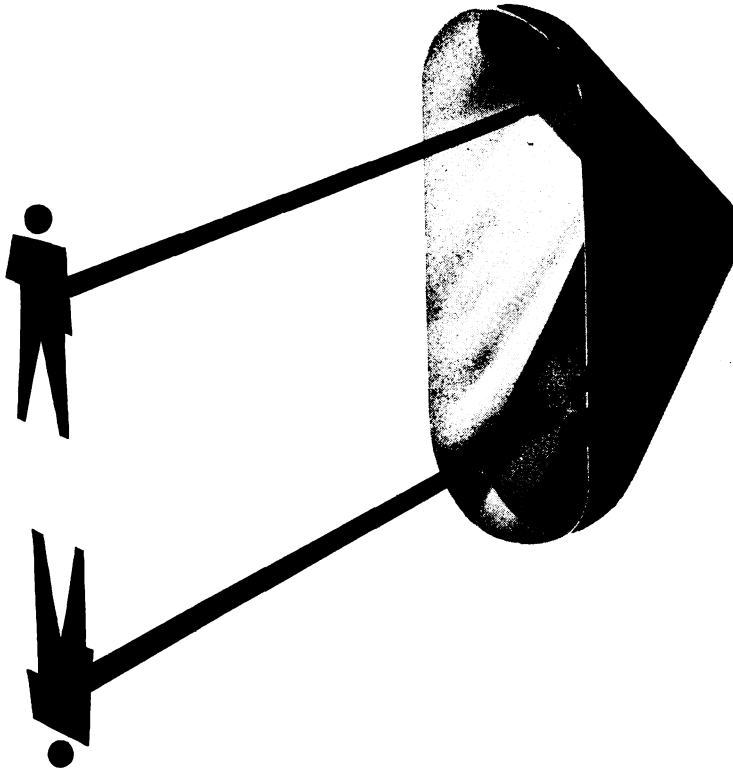
**POINT OF PRINCIPAL FOCUS.** The point to which parallel rays of light converge or from which they diverge when they have been acted upon by a lens or mirror. A lens has a single point of principal focus on each side of the lens; it has many focal points, depending upon the distance of the object from the lens (fig. 172).

**POLARIZED LIGHT.** In optics, light which vibrates in one direction only (in a single plane). Plane of polarization is the plane in which the polarized light vibrates. Light is polarized by natural materials (Iceland spar) or a manufactured product known as "Polaroid."

**POLARIZING FILTER.** A ray filter which polarizes the light passing through an instrument.

**PORRO PRISM.** One of two identical prisms used in the porro prism erecting system (fig. 190). It is a right angle prism with the corners rounded to minimize breakage and simplify assembly. See **PORRO PRISM ERECTING SYSTEM**.





RA PD 30580

**Figure 190 — Porro Prism**

**PORRO PRISM ERECTING SYSTEM.** A prism erecting system, designed by M. Porro, in which there are four reflections to completely erect the image. Two *Porro prisms* are employed. The line of sight is bent through 360 degrees, is displaced, but is not deviated.

**POSITIVE LENS.** See **CONVERGING LENS.**

**POWER.**

1. In a lens, power is a measure of ability to bend or refract light. It is usually measured in *diopters*.
2. In a telescope, power is the number of times the instrument magnifies the object viewed. For example, with a 6-power instrument, an object 600 yards away is enlarged six times, or it appears as it would to the naked eye if it were at a distance of only 100 yards.

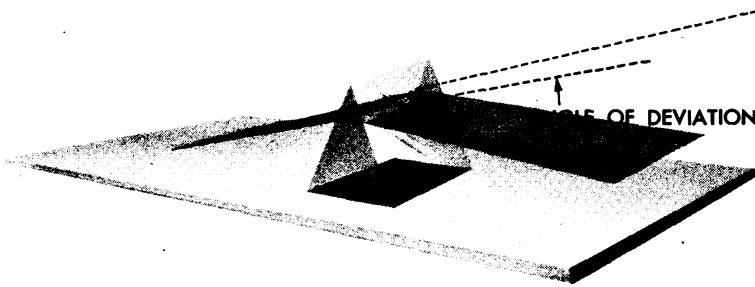
*Glossary*

**PRESBYOPIA.** Sometimes called oldsightedness. A defect of vision due to advancing age. The crystalline lens no longer is capable of accommodating for nearby objects and these objects cannot be seen distinctly. It is corrected by the use of "bifocal" lenses, lenses with a small area ground to a steeper curvature.

**PRINCIPAL AXIS.** A straight line connecting the centers of curvature of the two refracting surfaces of a lens. In a mechanical sense, a line joining the centers of a lens as it is placed in the mount.

**PRINCIPAL FOCUS.** See POINT OF PRINCIPAL FOCUS.

**PRISM.** A transparent body with at least two polished plane faces inclined toward each other, from which light is reflected or through which light is refracted. When light is refracted by a prism, it is deviated or bent toward the thicker part of the prism (fig. 191). See ABBE PRISM ERECTING SYSTEM; AMICI PRISM; COINCIDENCE PRISM; DOVE PRISM; OBJECTIVE PRISM; PENTA PRISM; PORRO PRISM; RHOMBOIDAL PRISM; RIGHT-ANGLE PRISM; TRIPLE MIRROR.



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**Figure 191 – Prism**

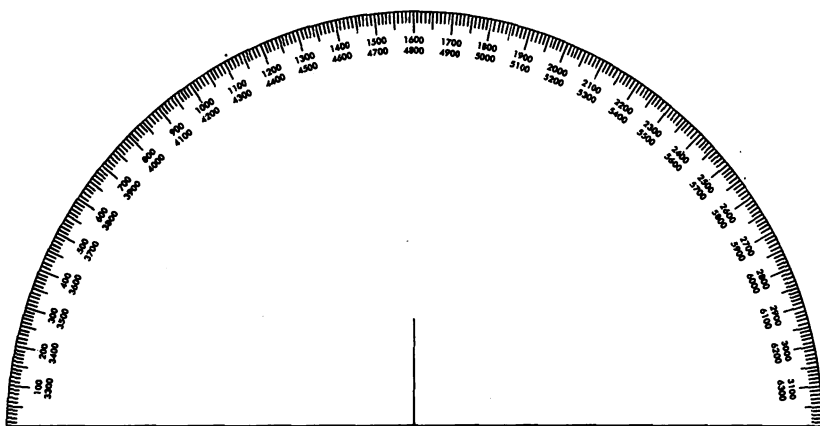
**PRISM DIOPTER.** A unit of measure of the refracting power of a prism. One diopter is the power of a prism to deviate a ray of light by one centimeter at a distance of one meter from the prism.

**PRISM OFFSET.** The term applied to certain telescopes having a characteristic offset due to the mounting of the prism erecting system in the body of the instrument.

**PRISMATIC.** Pertaining to a prism, or the effects produced by prisms.

**PROBABLE ERROR.** An allowance based on average errors made by a large group of range finder operators. It will be exceeded as frequently as it is not.

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Figure 192 — Protractor

**PROTRACTOR.** An instrument for measuring or laying off angles mechanically. It consists of a graduated arc or semi-circle, sometimes containing a radial arm (fig. 192).

**PUPIL.** The dark center of the eye; it is the aperture through which light enters the eye.

**QUADRANT.**

1. A quadrant of a circle; a sector, arc, or angle of 90 degrees.
2. An instrument for measuring or setting vertical angles, such as a *gunner's quadrant* or a *range quadrant*.

**QUADRANT ANGLE OF ELEVATION.** See **ANGLE OF ELEVATION**.

**RADIAN.** An angle included within an arc equal to the radius of a circle. It is equal to  $57^{\circ} 17' 44.8''$ .

**RADIANT ENERGY.** Energy or force that is radiated or thrown off in all directions by its source. Light is a form of radiant energy.

**RANGE.** Distance. The horizontal distance from a gun to its target; the distance from an observer to a designated object. It is usually measured in yards.

**RANGE FINDER.** An optical instrument used to determine the distance of an object or target by triangulation.

**RANGE QUADRANT.** An instrument used to measure range or elevation in laying a gun.

**RAY.** See **LIGHT RAY**.

**RAY FILTER.** See **FILTERS**.

**REAL IMAGE.** See **IMAGE**.

**RECTILINEAR.** In a straight line. When applied to a lens, it indicates that images of straight lines produced by the lens are not distorted.

**RECTILINEAR PROPAGATION.** Straight line travel; refers to the fact that light travels in a straight line when traveling through a medium of constant density.

**REFLECTED RAY.** The ray of light leaving a reflecting surface, representing the path of light after reflection (fig. 147).

**REFLECTION.** Light striking a surface and returning or "bouncing back" into the medium whence it came. *Regular reflection* from a plane polished surface, such as a mirror, will return the major portion of the light in a definite direction lying in the plane of the incident ray and the normal. See **ANGLE OF REFLECTION**. Regular reflection will form a sharp image. *Diffuse reflection* occurs when the surface is irregular and the reflected light diverges from each point as if it were a separate reflecting surface. Diffused rays go in many directions and will not form a distinct image.

**REFRACTING POWER.** The power of a lens or lens system to converge or diverge light. See **DIOPTER**.

**REFRACTION.** The bending of light which occurs when a ray of light passes obliquely from one medium to another of different density. See **ANGLE OF REFRACTION** and **ANGLE OF DEVIATION**.

**REFRACTIVE INDEX.** See **INDEX OF REFRACTION**.

**REGULAR REFLECTION.** See **REFLECTION**, above.

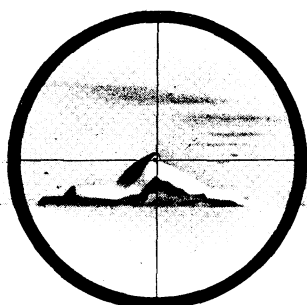
**RELIEF.** Effect of stereoscopic or three-dimensional vision; sharpness of outline due to contrast of the object standing out from a background.

**RESOLUTION.** In optics, the ability of a lens system to reproduce an image in its true sense.

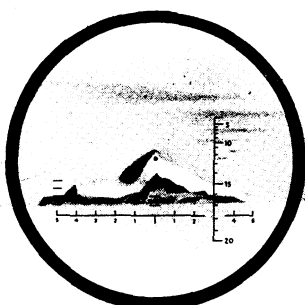
**RESOLVING POWER.** A measure of the ability of a lens or optical system to form separate images of two objects close together. No lens or optical system can form a perfect image of a point; it will appear as a small disk surrounded by concentric circles. If two points are so close together that the disks overlap, the points cannot be distinguished separately; they cannot be resolved. Increasing the lens diameter decreases the size of the disks. Thus, resolving power is the angle subtended by two points which are just far enough apart to permit resolution. This angle is termed the *limiting angle of resolution*.

**RETAINING RING.** A thin ring threaded on the outside surface. It is screwed into a tube, cell, or other body member of an optical instrument to retain or hold a lens or other part in fixed position.

**RETICLE.** Marks or pattern placed in the focal plate of an optical instrument which appear to the observer to be superimposed upon the field of view (fig. 193). They are used to determine the center of the field or to assist in the gaging of distance, determining leads, or measurement. The reticle may be a pair of cross lines composed of fine wire or may be etched on a glass plate with plane parallel surfaces. If it is etched on glass, the entire piece of glass is referred to as the reticle. The old forms of this term are reticule and graticule. (Also see figure 101.)



CROSS HAIR OR  
CROSS LINE



MIL SCALE AND INVERTED  
LEAF

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**Figure 193 — Reticle Patterns Superimposed on Image of Object**

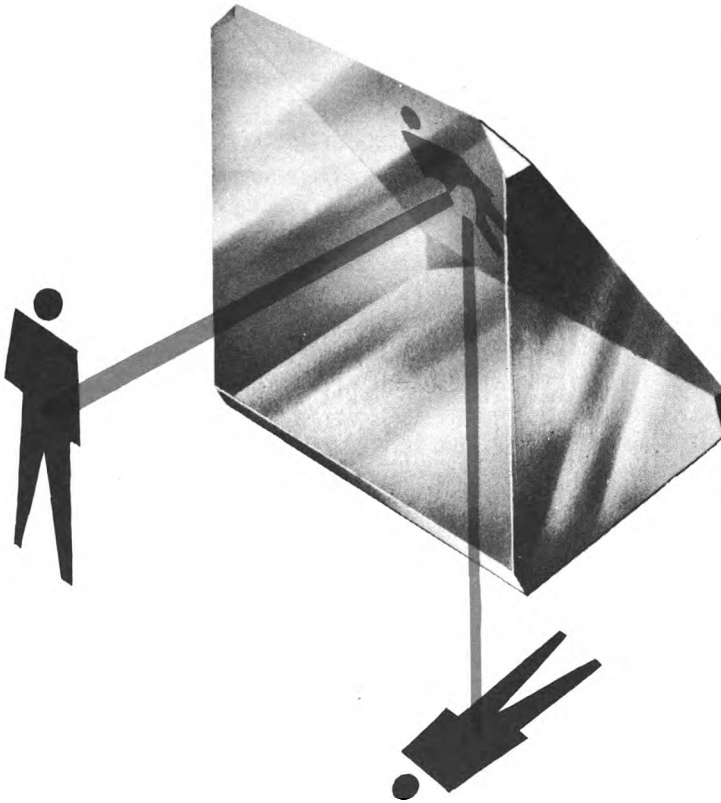
**RETINA.** The light sensitive inner coat or tunic of the eyeball upon which the image is formed by the lenses of the eye. It contains the visual cells called the *cones* and *rods* (fig. 73).

**REVERSION.** Turned the opposite way so that right becomes left and vice versa. It is the effect produced by a mirror in reflecting an image.

**REVERTED IMAGE.** An image the right side of which appears to be the left side and vice versa.

**RHOMBOIDAL PRISM.** A prism with four parallel sides and two slanting or oblique, parallel ends. It will divert the path of light entering its ends without changing the form of the light. Rhomboidal prisms may be rotated on the centers of their ends to divert the lines of sight to permit interpupillary adjustment of the eyepieces of a binocular instrument such as a stereoscopic height finder (fig. 89).

**RIGHT-ANGLE PRISM.** A type of prism used to turn a beam of light through a right angle ( $90^\circ$ ) (fig. 194). It will invert (turn



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**Figure 194 — Right-angle Prism**

upside-down), or will revert (turn right for left), according to the position of the prism, any light reflected by it.

**ROD.** One of the two types of light-sensitive elements or visual cells in the retina of the eye which permit sight. The rods are associated with night vision and sight under other conditions of weak light. They also detect motion. For seeing in weak light, they are stimulated by a substance known as *visual purple*. The other type of visual cell is termed the *cone* (fig. 73).

**ROOF-ANGLE PRISM or ROOF PRISM.** See **AMICI PRISM**.

**ROTATING PRISM.** See **DOVE PRISM**.

**ROTATING WEDGE.** A circular optical wedge mounted to be rotated in the patch of light to divert the line of sight to a limited degree. See **CORRECTION WEDGE**, **MEASURING WEDGES**.

**ROUGE.** A material for the polishing of optical glass, made principally from red oxide of iron. The name is also applied to polishing

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materials which are not red, such as black rouge and white rouge.

**SCLERA.** The outer of the three coats or tunics of the eyeball. It is tough, white, and flexible and is the white portion of the eye normally seen. The slightly protruding transparent portion of the center front of the eye, the *cornea*, is part of this coat (fig. 70).

**SECOND.** A unit of measurement of part of a circle equal to one-sixtieth of a minute, or  $\frac{1}{3600}$ th part of a degree.

**SELECTIVE ABSORPTION.** See **ABSORPTION**.

**SELECTIVE REFLECTION.** See **ABSORPTION**.

**SEPARATOR.** Also known as **SPACER**. A hollow, tubular part used to separate two lenses at a definite distance.

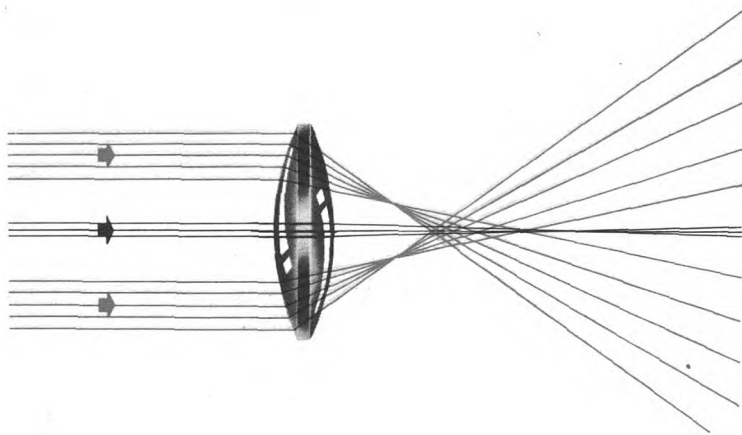
**SIGHTING INSTRUMENTS.** Devices or instruments designed to aid in the pointing of a weapon.

**SINE.** The sine of an angle is the side opposite the angle divided by hypotenuse (the long side opposite the right angle of a right angle triangle).

**SITE (Location).** See **ANGLE OF SITE**.

**SOFT COAT.** A term designating the soft coating applied to coated optics to differentiate between the harder and more durable coating known as *hard coat*.

**SPECTRUM.** The band of color produced by a prism in dividing white light into its components. The rainbow is an example; dispersion produces this spectrum. See **ELECTROMAGNETIC SPECTRUM**.



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**Figure 195 — Spherical Aberration**



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**SPHERICAL ABERRATION.** The aberration of a lens which results when rays of light which pass through a lens near its edge are converged to a point nearer the lens than those rays passing through near the center (fig. 195). The effect is poor definition of the image.

**SPLIT FIELD.** The field of view as seen when observing through a coincidence range finder. It is formed by uniting halves of the images produced by the two objectives. The half images are separated by the *halving line*.

**STADIA SCALE.** Graduations on a reticle which in conjunction with a rod of definite length can be used to measure distances.

**STANDARD LETTERS.** Letters of specific size which are viewed at specified distances to test the keenness of sight.

**STEREO-ACUITY.** Keenness or sharpness of sight in depth or three dimensions.

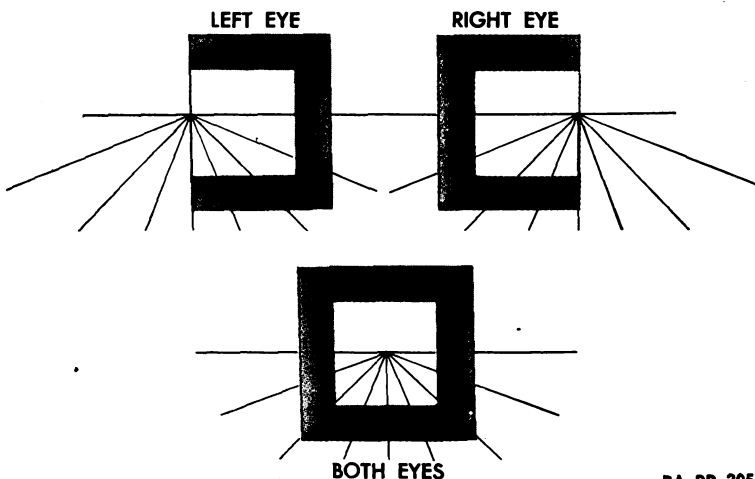
**STEREO-VISION.** See STEREOSCOPIC VISION.

**STEREOGRAM.** A card containing two pictures taken from different angles (corresponding to the spacing between the pupils of the eyes), which when viewed through a stereoscope, present a single image with the illusion of depth or three dimensions.

**STEREOPSIS.** See STEREOSCOPIC VISION.

**STEREOSCOPE.** A binocular instrument used to view stereograms.

**STEREOSCOPIC CONTACT.** A term applied to the action of bringing the target into the same apparent distance plane as the



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Figure 196 — Stereoscopic Effect

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central measuring mark of the reticle in the use of a stereoscopic height finder.

**STEREOSCOPIC EFFECT.** The sense of relief or solidarity resulting when an object is viewed by both eyes, due to the fact that each eye views the object from a slightly different angle (fig. 196).

**STEREOSCOPIC POWER.** The gain in stereoscopic effect afforded by a magnifying binocular instrument as compared with the ability of the naked eyes. This power will vary with the separation of the objectives and the power of the instrument.

**STEREOSCOPIC VISION.** Vision in depth or three dimensions due to the spacing of the eyes. This spacing of the eyes permits them to see objects from slightly different angles. They get a better impression of the shape, depth, and position of an object with relation to other objects (fig. 75).

**STRABISMUS.** Affection of the eye in which the lines of sight cannot be directed to the same object at once because of abnormal contraction or relaxation of one or more of the muscles controlling the movement of the eyeball. Also known as squint or cross-eye.

**STRAIN.** A tension or fault in optical glass caused by internal stress and brought about by improper cooling or annealing during manufacture of the glass.

**STRIAE.** Localized variations in the index of refraction of a piece of optical glass, usually occurring in streaks. It is caused by improper mixing of the ingredients during manufacture.

**SUNSHADE.** A tubular projection provided to protect the objective from the direct rays of the sun (fig. 111).

**SURFACE PLATE.** A plate having a very accurate plane surface used for testing other surfaces or to provide a true surface for accurately locating testing fixtures. It is usually mounted on three adjustable legs so that it can be accurately leveled in a horizontal plane.

**TANGENT.** A straight line which touches a curve but does not cut in.

**TELESCOPE.** An optical instrument containing a system of lenses, usually with magnifying power, which renders distant objects more clearly visible by enlarging their images on the retina of the eye, or which superimposes a reticle pattern on the image of the object to assist in the gaging of distance.

**TOTAL INTERNAL REFLECTION.** Reflection which takes place within a substance because the angle of incidence of light striking the boundary surface is in excess of the critical angle. See **CRITICAL ANGLE**.

**TRAJECTORY.** The curved path through the air described by a

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projectile in its flight (fig. 146).

**TRAVERSE.** Movement in azimuth; rotation in a horizontal plane.

**TRIPLE MIRROR.** A prism with four triangular surfaces arranged like two triangular roofs placed at right angles to one another. This prism has the unique property of deviating, through an angle of 180 degrees, any ray of light entering it (fig. 109).

**TRIPLET.** A three-element compound lens with all three elements cemented together (fig. 156).

**TRUE NORTH.** Geographic north; the direction of the geographic north pole from a point on the earth's surface.

**UNIT OF CORRECTION.** An arbitrary scale graduation as laid off on the correction wedge scale of a range finder.

**UNIT OF ERROR (UOE).** Unit of measurement corresponding to 12 seconds of arc. When checking the accuracy of an observer's readings of range, as determined by a range or height finder, it is necessary to have some unit of measure. It has been determined by test that the mean error of the normal, well-trained observer under good conditions of observation should not exceed 12 seconds of arc for a series of readings, regardless of the range involved. This mean error is taken as the basis for determining the accuracy of range and height finder readings. The unit of error (UOE) is the unit of measure arbitrarily selected and all errors in range and altitude readings are converted to this unit during analysis.

**VELOCITY OF LIGHT.** The speed of light. It is numerically equal to the frequency multiplied by the wave length. The accepted velocity of light as used in calculations is 186,000 miles per second. Precise measurements of the speed of light in vacuum show it to be several hundred miles per second greater than this figure.

**VERTEX.** Highest or lowest point on the axis of a convex or concave mirror or lens.

**VERTICAL TRAVEL.** Movement of the line of sight of an optical instrument or gun in a vertical plane.

**VIRTUAL BASE.** The actual base or base line of a range or height finder multiplied by the power of magnification of the instrument.

**VIRTUAL IMAGE.** The image formed by a diverging lens. It is

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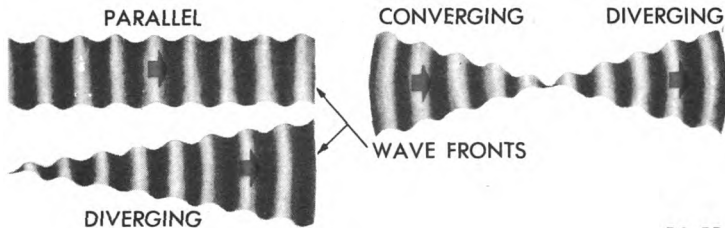
formed by rays which apparently meet at the image. It cannot be thrown upon a screen. It exists only in the mind of the observer (fig. 176).

**VISUAL ACUITY.** Acuteness or sharpness of sight.

**VISUAL PURPLE.** A substance surrounding the rods in the retinas of the eyes and stimulating them for keener sight under poor light conditions.

**VITREOUS HUMOR.** A transparent, jelly-like substance with which the rear and greater portion of the eye is filled and which is part of the refracting mechanism of the eye (fig. 70).

**WAVE.** Vibration; a form of movement by which all radiant energy of the electromagnetic spectrum is assumed to travel.

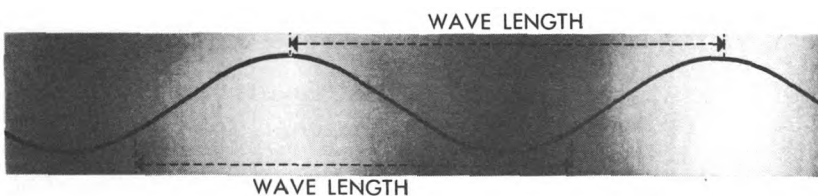


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**Figure 197 — Waves and Wave Fronts**

**WAVE FRONT.** A surface normal (at right angles) to a bundle of rays as they proceed from a source. The wave front passes through those parts of the waves which are in the same phase and go in the same direction. For parallel rays, the wave front is a plane; for rays diverging from or converging toward a point, the wave front is spherical (fig. 197).

**WAVE LENGTH.** Length of a wave measured from any point on



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**Figure 198 — Wave Length**

one wave to the corresponding point on the next wave; usually measured from crest to crest (fig. 198). Wave length determines the nature of the various forms of radiant energy which comprise the electromagnetic spectrum; it determines the color of light.

**WEDGE.** An optical element with plane inclined surfaces. Usually the faces are inclined toward one another at very small angles. Wedges divert light toward their thicker portions. They may be circular, oblong, or square. See **CORRECTION WEDGE**; **MEASURING WEDGE**.

**WHITE LIGHT.** Light, such as sunlight and daylight, which is composed of all the different wave lengths of the spectrum.

**WINDOW.** A piece of glass with plane parallel surfaces used to admit light into an optical instrument but exclude dirt and moisture. Also see **CORRECTION WINDOWS**.

**WORM.** A shaft with a gear in the form of a screw which meshes with a wormwheel. The axes of the worm and wormwheel are generally perpendicular to each other.

**WORMWHEEL.** A gear designed to mesh with a worm.

**Y-AZIMUTH.** The azimuth reading taken from the Y-North direction. See **Y-NORTH**.

**Y-NORTH.** The north direction as determined by the grid lines on a map. The United States is laid out in seven grid zones. The central grid line of each of these zones points to True North. The other grid lines being parallel to the central grid line will, due to the spherical shape of the earth's surface, not lie in a true north-south line. The deviation between True North and grid north due to this curvature will never exceed three degrees.

## CHAPTER 9 — REFERENCES

## 125. PUBLICATIONS INDEXES.

The following publications indexes should be consulted frequently for latest changes or revisions of references given in this section and for new publications relating to materiel covered in this manual:

- a. Ordnance supply catalog index (index to SNL's) ..... ASF Cat  
ORD 2
- b. Ordnance major items and combinations, and pertinent publications ..... SB 9-1
- c. List of publications for training (listing CCBP's, FM's, FT's, MTP's, TB's, TM's, TR's, TC's, and LO's) ..... FM 21-6
- d. List of training films, film strips, and film bulletins ..... FM 21-7
- e. Military training aids (listing graphic training aids, models, devices, and displays) ..... FM 21-8
- f. List and index of administrative and supply publications (listing new AR's, Cir's, GO's, and WDB's, T/O&E's, T/O's, T/E's, T/A's, T/BA's, MR's, RR's, WDP's, SB's, MWO's, and forms) ..... WD Pam 12-6

## 126. EXPLANATORY PUBLICATIONS.

- a. The instrument repairman ..... TM 9-2602
- b. Stereoscopic tester M1A1 and stereoscopic trainers M2, M6, and M7 ..... TM 9-654
- c. Dictionary of United States Army terms ..... TM 20-205

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